THESIS FOR THE DEGREE OF LICENTIATE OF ENGINEERING

Circular design in practice

Towards a co-created circular economy through design

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Abstract

In the efforts to stimulate sustainable development, the circular economy represents the most recent attempt to reduce the pressure on the environment by attaining harmony between the economy, environment and society. In theory, this is accomplished by establishing ‘closed-loop’ flows of resources in a way that enables businesses and society to reap benefits from maintaining products, components and materials at their highest utility and value, while reducing the generation of waste.

The circular economy offers considerable potential to address the environmental challenges in the design of products and the built environment, yet there are also a number of technical and non-technical challenges to overcome in its implementation. For designers such as industrial designers and architects, it means that the entire lifecycle including the design, production, use and waste phases need to be addressed holistically, and long-lasting collaborations need to be fostered in design endeavours to enable circularity on a systemic level. To date, there have been limited empirical studies into the implications of the circular economy for the practice of design.

Therefore, this thesis set out to examine how the concept of a circular economy is currently being operationalised within design practice and explore what design knowledge, tools and methods are needed to support design practice and curricula in designing for a circular economy. The thesis builds on three studies. Study A investigated the current interpretations and operationalisation of the circular economy in design practice across the disciplines of architecture and industrial design; Study B explored the role of stakeholder collaboration and co-creation in facilitating circular design innovation; and Study C explored what knowledge, tools and strategies could further support design for a circular economy in practice.

The findings indicate that the circular economy is a multi-faceted challenge that expands the scope of design projects and drives the integration of new knowledge and skills in design practice. The circular economy shifts the focus of designers away from the creation of physical artefacts and towards the creation of systems, business models, collaborative networks and future visions; thus, ultimately helping clients to look ahead and render the pathways towards circularity tangible. The circular economy requires extensive stakeholder collaboration during (and after) the design process, and the results indicate that establishing this collaboration can be regarded as integral components of circular design and as intangible design outcomes. In this regard, participatory design approaches are found to be important in fostering awareness and knowledge of circularity and promoting collaboration between actors. Finally, the ambiguity encompassing the circular economy calls for a holistic design approach and universal design frameworks and language to ensure that the ‘version’ of a circular economy that society will see in the future is the one that aligns with the underlying goals of sustainable development.

To conclude, the findings of this thesis contribute to a better understanding of how the concept of a circular economy is implemented across design practice and identifies pathways to further advance circular design.

Keywords: circular economy, circular design, circularity, circular business models, industrial design, architecture, design for sustainability, design practice, collaboration, co-creation, co-design

Preface

"Waste and pollution are not accidents, they are consequences of decisions made at the design stage." (Ellen MacArthur Foundation, n.d.)

This rather bold sentence has stuck with me since the first day I stumbled upon it during this PhD journey. One might question if it is reasonable to place such emphasis on the role of design. Is design not just one link in a very complex chain of factors and actors that define our physical environment and contribute to the global challenges of today? What influence do designers really have in this process? Whichever way you look at it, it is a fact that designers frequently make decisions that are irreversible, have long-term social and ecological impact, and can shape and steer the (consumption) behaviour of people.

In the face of growing environmental and social challenges, the field of sustainable design has advanced substantially in recent years to the extent that sustainability concerns are no longer considered as a 'bonus' and are a central component in the majority of design projects. Sustainable design has appeared in many shapes and forms, and the latest addition to the discourse is that of 'circular design', which at first glance, appears as a seemingly radical different approach. The discussion about resource circularity has made me ponder over the question where we are in (design) practice and if people 'talk the talk' or 'walk the walk', and what is needed in terms of knowledge and tools to tackle the complex interdisciplinary challenges that it imposes.

Manzini (2007) discussed three non-catastrophic scenarios for a sustainable future. One where sustainability is enforced through policy and regulations, where people make the right choices because there are rules that make them do so. In the second they do so out of choice, with no external imposition. In the third they do so without having to choose, simply because it is natural for everybody to act in a sustainable way, in the best interest for themselves, society and for the planet. Although the first scenario is likely to happen in the face of imminent ecological disaster, it will be a sad and repressive reality of sustainability. The third one would be optimal, but is it realistic to think that this might ever be possible? The second one requires everyone to be capable of choosing and to act as designers, to find solutions for a complex reality with many compromises. I believe that this is the way forward.

When I started my studies in industrial design I was fascinated by the (seemingly endless) opportunities of solving 'real' problems and improving people's wellbeing, thus making the world a better place. I remember my first Ipod (the Nano, 1st generation, black). The sleek, compact, and minimalistic design, the intuitive user interface, the effortless user experience, the impressive storage capacity of 2GB, it was fascinating to see so much technology in a box half the thickness of a matchbox.

Throughout recent years I cannot help becoming increasingly doubtful whether it is not better to not design anything at all. Today I think that if I should not contribute by designing 'stuff', perhaps there is a possibility to contribute through 'designing' better ways of designing, or supporting people with the means to design better. This thesis is perhaps a very preliminary and 'pocket-sized' start to this journey.

Acknowledgements

If you read this and have been part of my PhD journey, know that I appreciate you very much. For all of you who supported me throughout this undertaking in recent years, I am grateful and wouldn't have been able to get here without you. Special thanks to my supervisors and examiner, who made this PhD possible and supported me in my development to become a better researcher. I am thankful to the funding organizations and project partners who made this research possible.

Research context

The thesis work has been conducted at the Department of Architecture and Civil Engineering at Chalmers University of Technology. The starting point for this research was the project 'the Circular Kitchen', funded by the EIT-Climate KIC. The project is a collaboration between two universities (Chalmers University of Technology and Delft University of Technology) and various industry stakeholders (including kitchen furniture manufacturers, appliance manufacturers and housing agencies.

The project aims to (1) gather knowledge on existing resource flows and consumption patterns in the context of kitchens and (2) explore the potential of circularity in the kitchen industry and generate knowledge for kitchen design solutions and business models based on the concept of a circular economy. In addition, the project strived, in cooperation with the stakeholders, to co-create, develop and test the generated design solutions in practice.

This project also offered the opportunity to explore and learn from a circular economy-oriented design and development project taking place in a real-life setting, spanning multiple years, involving numerous stakeholders, and considering both the design and business context. This sparked the interest for a wider investigation into the concept of a circular economy, the (practical) implications for design (and designers), and the role of collaboration within design for a circular economy.

Included publications

Paper A (Published)

Dokter, Giliam, Thuvander, L., & Rahe, U. (2021). How circular is current design practice? Investigating perspectives across industrial design and architecture in the transition towards a circular economy. Sustainable Production and Consumption, 26, 692–708. https://doi.org/10.1016/j.spc.2020.12.032

Contribution: Dokter planned the study with input from Thuvander and Rahe. Dokter performed the data collection and analysis and wrote the paper. Thuvander and Rahe reviewed the paper.

Paper B (In press)

Dokter, G, Andersson, S., Thuvander, L., & Rahe, U. (2020). Co-creation – a facilitator for circular economy implementation? A case study in the kitchen industry. In N. Nissen & M. Jaeger-Erben (Eds.), PLATE Product Lifetimes And The Environment 2019 – Conference Proceedings. TU Berlin University Press. ISBN 978-3-7983-3125-9 (online).

Contribution: Dokter and Andersson planned the study with input from Thuvander and Rahe. Dokter and Andersson performed the data collection and analysis together. Dokter wrote the paper. Andersson, Thuvander and Rahe reviewed the paper.

Paper C (Published)

Dokter, G., van Stijn, A., Thuvander, L., & Rahe, U. (2020). Cards for circularity: Towards circular design in practice. IOP Conference Series: Earth and Environmental Science, 588(4). https://doi.org/10.1088/1755-1315/588/4/042043

Contribution: Dokter and van Stijn planned the study with input from Thuvander and Rahe. Dokter and van Stijn developed the tool used for the data collection. Dokter performed the data collection and analysis. Dokter lead the writing of the paper with contributions of van Stijn. Thuvander and Rahe reviewed the paper.

Additional publications

Hagejärd, S., Dokter, G., Rahe, U., & Femenías, P. (2021). My apartment is cold! Household perceptions of indoor climate and demand-side management in Sweden. Energy Research & Social Science, 73, 101948. https://doi.org/10.1016/j.erss.2021.101948

Terminology

Circularity	A term referring to the degree or the proportion of resource flows with circular characteristics
Design	The application of intent and the process through which people create material, spatial, visual and experiential environments
Designer	Anyone who performs design
Design tool	An object, form of media or system that supports the act of designing, or extends the designers capability to do so
Design method	A formalized representation of a design activity that functions as a mental tool to support designers to (learn how to) achieve a certain goal, in relation to certain circumstances and resources available
Design process	A series of abstracted phases and iterative steps that describes the development of an artefact or solution in which the degree of abstraction is gradually reduced in order to fulfill internal or external requirements or specifications
Design strategy	A plan in which design stages and activities are executed to achieve a certain goal
Supply chain	The entire chain of activities from the perspective of all actors involved that are needed to bring the artefact from conception to the final consumer
Stakeholder	An individual or an organization who can affect, or be affected, by an organization, strategy, product or project
Value chain	The chain of activities from the perspective of an individual organization to bring an artefact from raw material to final embodied state. Each step in the chain represents a value activity that adds value to the final artefact.

Acronym

CE	Circular economy
CfC	Cards for Circularity
DfS	Design for Sustainability
DfD	Design for Disassembly
EoL	End-of-life
LCA	Life cycle analysis
PSS	Product-Service System

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1. Introduction

The industrialised economies of today are based on the notion of turning resources into waste. Raw materials are extracted from the earth and transformed into artifacts such as products and buildings, which are then sold, used and discarded (or deconstructed) when required. This economic model, also referred to as the linear economy, is fundamentally based on a take-make-dispose principle and relies on the perpetual consumption of resources to sustain economic viability. Consequently, this model has contributed to some of the major global challenges faced by human society today such as the depletion of finite resources, significant waste issues and environmental degradation. Despite substantial efforts and calls to promote sustainable development in recent decades, illustrated by reports such as 'Limits to Growth' (Meadows et al., 1972) and 'Our Common Future' (WCED 1987), it is apparent that these efforts have not led to appropriate measures or the imagined reductions in negative environmental impacts (Sneddon et al., 2006; Murray et al., 2017). Instead, the global demand for material resources has steadily increased over recent decades and is projected to double until 2050 (Krausmann, Lauk, Haas, & Wiedenhofer, 2018). In 2005, as little as 6% of all materials processed by the global economy were recycled and contributed to the closing of resource loops (Haas, 2015).

In recent years, a radically different economic model has gained traction in politics, academia and industry, namely that of a circular economy (CE). In a CE, the notion of waste is eliminated by maintaining products, components and materials at their highest utility and value at all times (Webster, 2015), which can be achieved, for example, through long-lasting design, maintenance, repair, reuse, remanufacturing and recycling (Geissdoerfer, Savaget, Bocken, & Hultink, 2017). The ultimate objective of this model is to achieve the decoupling of economic growth from natural resource depletion and environmental degradation (Liu et al. 2009; Xue et al. 2010). Although the idea of closing resource loops is not necessarily novel, it has been popularised in recent years by NGOs (non-governmental organisations) such as the Ellen MacArthur Foundation and has gained a place on political agendas across Europe, as it is seen as a way of implementing sustainable development without limiting economic growth (European Commission, 2014a, 2020a).

Despite the ambitious plans on a European level (e.g., increasing reuse and recycle rates of municipal waste to 65% and reducing landfill production to 10% by 2030; European Commission 2019), the realisation of a CE is still in its early stages (Ghisellini, Cialani, & Ulgiati, 2016; McDowall et al., 2017). This limited progress is often related to technical barriers, for example, consumer products are not correctly designed to support longevity, maintenance, disassembly and reuse (Pheifer, 2017). Other studies indicate that the major barriers are not technical but rather of a cultural nature, such as the limited collaboration across value chains, hesitant company cultures and a lack of awareness and interest by consumers. Furthermore, an additional challenge for the implementation of a CE is that the concept itself is interpreted in different ways by different actors (Blomsma & Brennan, 2017) and the subject of conceptual and terminological unclarity and debate (Kirchherr, Reike, & Hekkert, 2017; Korhonen, Nuur, Feldmann, & Birkie, 2018). Therefore, the CE approach will not be immune to failures, misuse, ambivalence and greenwashing (Sauvé, Bernard, & Sloan, 2016).

This raises questions about 'what version' of a CE we will see in the near future, and whether the CE can deliver on its promise of addressing environmental concerns and establishing a systemic change in the way we view resources and their lifecycles, or whether it will lead to incremental changes at best with the CE becoming yet another 'buzzword of sustainability' (Kirchherr et al., 2017). It also raises questions concerning what role design could play in the transition to a CE, and what designers could do to contribute to the holistic implementation of the CE concept and address the barriers that currently exist.

Notwithstanding the ambivalence surrounding the CE, there seems to be a consensus in academia and politics that design plays an important role in the transition to a CE (De los Rios, Charnley, Sundin, Lindahl, & Ijomah, 2017; European Commission, 2020a). Design, defined as the process through which we create the material, spatial, visual and experiential environments, has a direct influence on the environmental impact of artifacts such as consumer products and buildings. This view is often supported by the claim that 80% of the environmental impact of products is determined in the design phase (European Commission, 2014c), and the role of design in the CE transition is also considered particularly impactful in the context of the built environment (European Commission, 2020b).

Yet, for designers, which includes both product designers and architects, the CE imposes many challenges that will require novel approaches. Designing products and buildings that function in a closed loop of resources will require designers to, more than ever, anticipate how such artifacts might function and change over time and conceptualise the entire lifecycle including the design, production, use and end-of-life (EoL) stage in a concurrent and coherent way. However, recent studies indicate that these technical challenges may not form the major barriers to a CE (Kirchherr et al., 2018; Ritzén & Sandström, 2017; Rizos et al., 2016). Instead, after decades of operating in traditional silos, the CE will now challenge companies to collaborate on a systemic level (Pieroni, McAloone, & Pigosso, 2019). After all, the successful implementation of a CE will not rely on individual actors becoming 'circular' but rather on the design of systems that are 'circular', which are dependent on numerous stakeholders and will also require new ways of working, new business partners, new roles for existing partners and new kinds of collaborations between stakeholders (Aminoff, Valkokari, & Kettunen, 2016). Hence, the success of design efforts focusing on CE will rely to a great extent on establishing resilient collaborative networks within the value chain in order to close the loop.

This draws attention to the role that designers (could) play in connecting actors and fostering collaboration for CE-oriented innovation and how this collaboration is approached within the design process. Furthermore, collaboration is not only important during the design process but also during and after the lifecycles of products, buildings, components and materials. In design, this represents both a challenge and an opportunity. Indeed, collaboration is nothing new to the design process, which has always been a dynamic process featuring teamwork, stakeholder interaction and the balancing of (often conflicting) demands. In recent decades, the scope of design has moved from object-centric thinking to system-based design approaches (Ceschin & Gaziulusoy, 2016). Designers, to an increasing extent, perform strategic activities such as developing strategic visions, facilitating dialogues between actors, business development and utilise participatory design approaches (e.g. codesign). Still, the success of design efforts is often measured in physical and tangible outputs, while in the context of a CE, the key to success is not solely the design of physical objects but rather the design of the network and its relationships (Pedersen & Clausen, 2019). The role that designers play as facilitators of collaborative design processes has been widely investigated in design research (Ezio Manzini, 2009) and, for example, in the context of whole system (Charnley, Lemon, & Evans, 2011) and participatory design (Luck, 2007) but to a limited extent in the context of the CE.

Thus far, previous studies regarding designing for a CE have primarily focused on developing methods, tools and frameworks to support circular design and investigated the changing roles and competencies required of designers in a CE (Andrews, 2020; N. M. P. Bocken, de Pauw, Bakker, & van der Grinten, 2016; De los Rios et al., 2017; den Hollander, Bakker, & Hultink, 2017; Mestre & Cooper, 2017; Moreno, De los Rios, Rowe, & Charnley, 2016; Sumter, Bakker, & Balkenende, 2018; Wastling, Charnley, & Moreno, 2018). The question that arises, therefore, is whether the available design knowledge, tools and methods sufficiently support design practice and curricula in tackling the complicated challenges encountered in practice, which often require interdisciplinary collaboration and co-creation. To date, most studies have been theoretical and conceptual. There has been a lack of empirical investigation into how the concept of circularity is interpreted and implemented in practice by designers, particularly case-based evidence in which both the contexts of design and business are considered.

1.1 Aim and research questions

This thesis aims to bridge the current knowledge gap between CE-related design theory and practice. The overall aim of the thesis is to investigate how the CE concept is currently interpreted and operationalised within the practice of industrial design and architecture and explore what knowledge, tools and strategies might further support design for a CE in practice. In addition, the thesis investigates the role of collaboration and co-creation in design practice as a way of facilitating CE-oriented innovation. By investigating how the concept of a CE is currently implemented, and to what extent this is done holistically and according to the underlying goals of the CE, the thesis seeks answers to whether discrepancies exist between CE-related design theory and practice and how such discrepancies might be addressed.

To address these aims, the following three research questions were formulated:

1. How is the concept of a CE currently interpreted and operationalised across the design practice of architecture and industrial design?

2. What is the role of stakeholder collaboration and co-creation in design practice as a way of facilitating CE-oriented innovation?

3. What knowledge, tools and strategies could further support design for a CE in practice?

1.2 Research scope

The research is positioned within the field of architecture and industrial design, which can be regarded as two separate but interrelated design disciplines that both play a vital role in achieving circularity in consumer goods and the built environment.

In this thesis, design practice is considered to be the practice of an individual whose occupation is that of a designer, and a design practitioner or design professional can be described as an individual whose occupational role is that of a designer. This thesis primarily focuses on the disciplines of industrial design and architecture as two creative disciplines that play an instrumental role in the transition to a CE in the European context to be able to address the environmental challenges in the design of consumer goods and the built environment (European Commission, 2020a). According to the Montreal Design Declaration ("Montreal Design Declaration," 2017), 'design' can be defined as the process through which people create material, spatial, visual and experiential environments. This thesis adopts this definition and, therefore, considers both industrial designers and architects to be designers.

There are also other design disciplines that are relevant to investigate in relation to the CE (e.g., fashion and textile design, interior design, interior architecture), but these are mostly out of the scope of this thesis. Nonetheless, the disciplines of architecture and industrial design also exhibit significant differences in relation to skills, scale, materiality, lifecycle perspectives, business context and regulatory constraints. The early models of the design process and design methods in architecture and engineering design (i.e., industrial design) were very similar but began to diverge in the 1970s in response to criticism from both design theorists and practitioners (Cross & Roozenburg, 1992). One of the criticisms was that the tree-like problem solving approach (breaking down the overall problem into sub-problems, sub-sub-problems, etc.) in engineering design was not suitable for architecture and planning (Alexander, 1965). Roozenburg and Cross (1991) urged the reintegration of the design models, and the development of a generalised and integrated model for design education, which was, for example, proposed as the basic design cycle in the book by Roozenburg and Eekels (1995). Nevertheless, in pursuit of circularity in products and the built environment, the disciplines of industrial design and architecture share the principles and overall aim of closing resource loops and ultimately decoupling economic growth from the consumption of resources.

As the transition to a CE is an interdisciplinary and large-scale systemic challenge (Murray, Skene, & Haynes, 2017) crossing disciplinary boundaries, it is not unlikely that designers will have to collaborate more extensively with relevant stakeholders and experts, along with increasing interactions and collaboration between different disciplines of design. Accordingly, by investigating the advancements and foci across design disciplines, there is the opportunity to study their interrelations and differences, which might provide insights into the overall development of design practices in relation to a CE and contribute to a more universal understanding of knowledge and strategies that can support design for a CE.

1.3 Research approach

Considering the fact that limited empirical research has been conducted into design for a CE, the research takes an overall explorative approach that can be roughly divided into two parts: the first part (Studies A & B) gathers insights by exploring how design for a CE is currently applied in practice and the second part (Study C) explores how efforts in practice can be further supported.

The notion of closed-loop resource flows and the role of design in formulating (tangible and intangible) solutions that can help transition to a CE in many ways represent a 'wicked problem'(Rittel & Webber, 1973). The transition to such a system is not (only) a challenge for design but rather a complex societal challenge that requires a systemic shift in the way people perceive and utilise resources and energy and which does not appear to have a clear solution that can be derived through scientific or engineering methods of inquiry. A wicked problem does not have a clear solution because it is part of the social fabric in which it sits (V. A. Brown, 2008), therefore, any solution to a wicked problem generates waves of consequences, yielding potentially undesirable repercussions and generating new problems that require new solutions.

Previous research has indicated that the main barriers for a transition to a CE are not technology-related but rather cultural (e.g., hesitant company cultures, a lack of consumer interest and awareness and a limited willingness to collaborate within the value chain; Kirchherr et al. 2018). Such 'wicked problems' cannot be accurately modelled and addressed through the reductionist approaches of science and engineering because of the conflicting perspectives of stakeholders, and, therefore, an engineering approach to such a problem would fail (Zimmerman, Forlizzi, & Evenson, 2007).

Although the idea of closed-loop resource flows is not novel, the recent resurgence of the concept in the form of the contemporary CE approach has been mostly led by practitioners in business and policy environments (e.g., see Ellen MacArthur Foundation 2013; European Commission 2014b, 2015). From a scholarly perspective, the conceptual discussions on the CE are still in their infancy (Korhonen, Nuur, et al., 2018) and a plurality of interpretations and definitions exist (Kirchherr et al., 2017). It is, therefore, not unlikely that early adopters and thought leaders in design practice have formed their own interpretations and definitions within the context of their own individual practices, which may not be self-evidently aligned with the underlying goals of a CE and sustainable development.

1.4 Outline of the thesis

This thesis is structured as follows. Chapter 2 presents an overview of previous research that is relevant for this thesis. Chapter 3 describes the overall research design and the methods chosen for the three separate studies that are included in this thesis. Chapter 4 summarises the findings of the studies. Chapter 5 discusses the findings in relation to the research questions and previous research and reflects on the research design and methods. Chapter 6 provides the conclusion and presents some directions for future research. In addition to these chapters, the three papers resulting from the different studies are appended.

2. Extended background

The following chapter summarises previous research that is relevant to the scope of this thesis. First, it provides a brief introduction into the concept of a CE and positions design for a CE within the overall domain of design for sustainability. Next, it summarises the current research on design for a CE across various scales of implementation. Finally, it addresses the role of designers and collaboration in relation to the CE.

2.1 The concept of a circular economy

The CE is an alternative economic model and industrial system that revolves around the notion of establishing cyclical flows of resources so that products, components and materials are maintained at their highest utility and value at all times (Webster, 2015), and the concept of waste is essentially eliminated. The CE is not necessarily a new concept but rather an umbrella concept (Blomsma & Brennan, 2017; Homrich et al., 2018) that synthesises a range of pre-existing principles for closing material loops and reducing the throughput of raw material and energy, these principles originate from (Benyus, 1997; Boulding, 1966; Braungart & McDonough, 2002; Lyle, 1994; Pauli, 2010; Stahel, 2010). Stahel and Reday-Mulvey (1976) were the first to refer to a closed-loop economy (Murray et al., 2017) by drawing from ideas of substituting energy with labour. In the early 1970s, rising energy prices and high unemployment were marked, and according to the architect Stahel, 'it took more labour and fewer resources to refurbish buildings than to erect new ones', which is a principle that holds true for any form of capital – from consumer goods such as mobile phone to buildings (p. 435) (Stahel, 2016). The uniqueness of the CE is that it combines the interconnected ideas of a closed-loop economy with a 'restorative' design approach (Murray et al., 2017).

In recent years, the Ellen MacArthur Foundation has popularised the concept further, emphasising the limits of the linear economy and conveying the business value of a CE (Ellen MacArthur Foundation, 2013). Their 'butterfly' diagram is widely used to communicate how the system of a CE functions and distinguishes between the biological and technical cycles (see Figure 1). Additionally, the foundation acts as a collaborative hub for businesses, policymakers and academia (Geissdoerfer et al., 2017). In fact, the contemporary CE discourse to a great extent has been led by practitioners in business and policy environments (e.g., see Ellen MacArthur Foundation 2013; European Commission 2014b, 2015), and the conceptual discussions from a scholarly perspective are still in an emerging state (Korhonen, Nuur, et al., 2018). The CE concept has its roots in many different disciplinary fields, and different interpretations and definitions co-exist within industry and academia (Blomsma & Brennan, 2017), which can make the concept difficult to grasp and capture in a single universal definition (Kirchherr et al., 2017; Korhonen, Honkasalo, & Seppälä, 2018).

Central to the CE concept are a set of circularity strategies, also referred to as 'resource life extending strategies' (Blomsma & Brennan, 2017) or 'resource value retention options' (Reike, Vermeulen, & Witjes, 2018), which have the capacity to preserve resource value. These strategies are typically grouped and conceptualised in various R frameworks from the 3Rs (reduce, reuse,

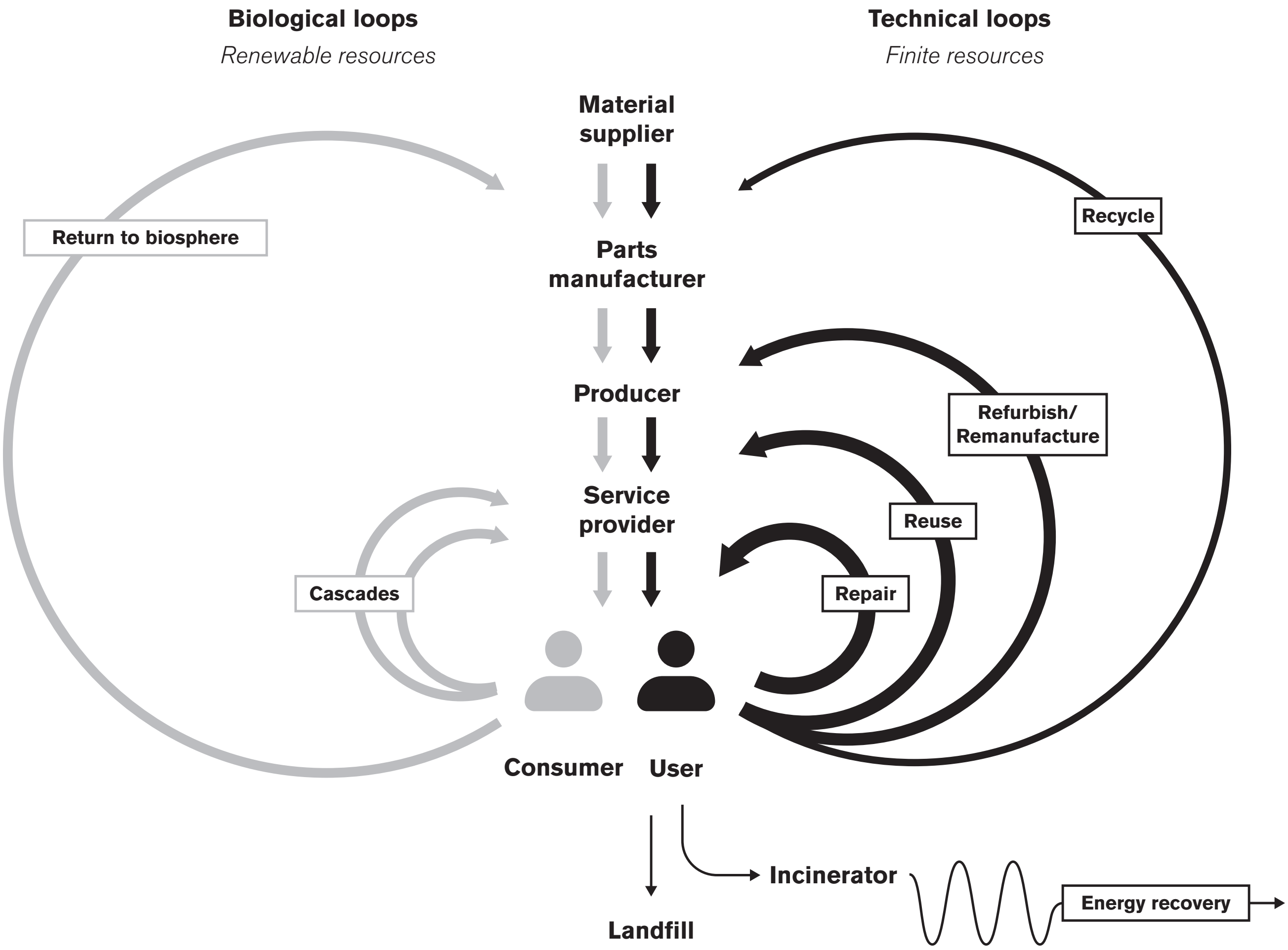

Figure 1. CE system diagram, adapted from the Ellen MacArthur Foundation (2013).

recycling), the 9Rs (Potting, Hekkert, Worrell, & Hanemaaijer, 2017) up to the 10 Rs (Reike et al., 2018), in which they are positioned in a hierarchy that is based on the extent to which they retain the value of the resources. For example, it is principally more resource-efficient and less wasteful to keep a chair performing its original function through repair and refurbishing than to break it down and recycle the materials (this would mean a greater loss of value and this process would require a larger amount of energy and resources). These strategies that focus on retaining resource value take a central role in the environmental policies of the EU (European Commission, 2020a) and some are also included in the 'waste hierarchy' (prevention, reuse, recycling, recovery, disposal) described in the European Waste Framework Directive (European Commission, n.d., 2008). From an EU policy perspective, scaling up the CE is seen as crucial to achieving climate neutrality by 2050 and implementing the 2030 Sustainable Development Goals (European Commission, 2014a, 2020a). Although the relationship between the CE and its potential to achieve various sustainable development targets has been discussed (Schroeder, Anggraeni, & Weber, 2019), the conceptual relationship between a CE and sustainable development is not entirely clear (D'Amato et al., 2017; Moreau, Sahakian, van Griethuysen, & Vuille, 2017). Some scholars have criticised the CE concept for the 'missing social dimension' (Murray et al., 2017) and for neglecting important social aspects such as challenging consumption behaviour and sufficiency-oriented lifestyles (Schulz, Hjaltadóttir, & Hild, 2019). Furthermore, Allwood (2014, 2018) criticised the CE for painting a beneficial picture of continuous material recycling and avoiding the impacts of new production, while in reality recycling remains energy intensive and almost always leads to the downgrading of the material quality (downcycling). Instead, Allwood emphasised the need for reducing the demand for materials, facilitating lifetime extension, reusing products and components and reusing materials without energy-intensive processing.

The CE is generally considered to operate at different implementation scales or 'levels', from the micro (products, components) and meso levels (buildings and eco-industrial parks) to the macro level (cities, built environment). On all scales, the ultimate aim of a CE is to decouple economic growth from the consumption of resources. In this regard, an often discussed factor in the CE discourse, particularly in relation to the micro level, is the role of service-based and circular business models, which aim to increase resource efficiency and lower environmental impacts through selling services rather than products (Nakajima, 2000). In product-oriented business models, companies are incentivised to maximise product sales. In service-oriented business models or product-service systems (PSS), companies are rewarded for providing a service which, in turn, incentivises the prolonging of the service life of products and ensures that products are used with as much cost and material efficiency as possible, as materials and consumables then become cost factors for the company rather than for the consumer (Tukker, 2015).

2.2 Sustainability in the design professions

Before discussing the implications of the CE for the various disciplines of design, it is relevant to provide a brief overview of the overall development of environmental concerns and sustainable development within the profession of design. Since the beginning of the Industrial Revolution, design has played a major role in societal and economic development (Press & Cooper, 2016).

Despite positive developments, design has also played a significant role in boosting the linear economy, fuelling consumerism and promoting malpractices such as planned obsolescence, which fostered 'the desire to own something a little newer and a little better, a little sooner than necessary' (Stevens, 2005). The focus on the 'styling' of products within the profession of industrial design developed in the first half of the 20th century to provide society and consumers with the illusion of change when design did not have any real contribution to make (Packard, 1960).

Early 20th century products were designed to enable maintenance and repair, parts were sold and scavenged at EoL and this, in combination with a low volumetric flow of products, meant that there was little waste. As planned obsolescence and the use of synthetic non-decomposable materials, composite materials and adhesives advanced, it became increasingly difficult to separate and reuse parts and materials, leading to increasing amounts of waste (Andrews, 2015). The development of official landfill sites is, thus, not surprising, as they offered a handy means of disposal which has further increased the cognitive gap between waste and society (Strasser, 1999).

From the middle of the 20th century, awareness of aspects of sustainability in the design professions further developed, encouraged by seminal design thinkers such as Buckminster Fuller (1969) and Viktor Papanek (1972). Papanek criticised design for being a 'harmful profession', stating that when everything becomes possible and all limitations are gone, design can easily become a never-ending search for novelty until newness-for-the-sake-of-newness becomes the only measure and the designer may become progressively more alienated from society and the functional complex (Papanek, 1972). Nonetheless, in the transition towards more sustainable modes of production and consumption, design is often considered to be of key importance, illustrated by the statement that 80% of the environmental impact of products is determined in the design phase (European Commission, 2014c; Graedel, Comrie, & Sekutowski, 1995). Some have also questioned the influence of design, considering that design is but one cog in the wheel of consumerism and the fact that designers are typically viewed as commercial actors who first and foremost respond to clients and consumers and who are trained to 'add value' to businesses (Thorpe, 2010).

Over time, different design for sustainability (DfS) approaches have been developed to address sustainability issues at the design stage, such as eco-design, cradle-to-cradle and bio-mimicry. Ceschin and Gaziulusoy (2016) discussed how over time DfS approaches have gradually expanded in scope, representing 'a shift from insular to system design innovation' (p.145). Where once the focus was on addressing sustainability in isolation (e.g., a single actor striving to improve the recyclability of a product and optimise product efficiency), it has shifted towards more systemic approaches, such as sustainable PSS (E. Manzini & Vezzoli, 2003), which involve various actors and a large degree of complexity. Concurrently, the role of designers has also shifted from object-centric design thinking to more system-based design approaches (A. I. Gaziulusoy & Brezet, 2015; E. Manzini & Vezzoli, 2003). To a greater extent, designers are challenged to perform strategic roles (Conny A. Bakker, 1995; Joore & Brezet, 2015; Sumter et al., 2018), establish future visions (Banerjee, 2008), facilitate strategic dialogues between actors (Meroni, 2008) and engage and include multiple actors in the design processes through participatory design methods such as co-creation and co-design (Bonsiepe, 2006; A. İ. Gaziulusoy & Ryan, 2017; Howard, 2004; Luck, 2007; Ezio Manzini, 2009; Elizabeth B.-N. Sanders & Stappers, 2008; Visser, Stappers, van der Lugt, & Sanders, 2005). Considering these developments, it is not surprising that the role of designers has become progressively more entangled with the roles of other actors (Joore & Brezet, 2015). The aforementioned DfS strategies (e.g., cradle-to-cradle, eco-design) support design efforts in sustainable development but can also be considered to be instrumental for design practice in the context of the transition to a CE (Ceschin and Gaziulusoy, 2016).

2.3 From design for sustainability to design for a circular economy

A distinction should be made between sustainable development from the perspective of the current linear economy and that of the CE. Sustainable development from the perspective of the current linear economy may emphasise relative approaches such as waste reduction, recycling and the reduction of pollution (Sauvé et al., 2016). Design strategies such as, for example, green design (Burral, 1991; Mackenzie, 1997) and eco-design are considered to be relative approaches and have, therefore, been criticised for being 'less bad' rather than good (Braungart & McDonough, 2002; Braungart, McDonough, & Bollinger, 2007). The CE, in contrast, assumes an absolute approach that does not aim to optimise the current state but rather rethink the system starting from the notion of a closed loop of resources in which the notion of waste should essentially not exist. Den Hollander discussed how current definitions (e.g., the European waste directive) still rely on the assumption that everything at some point turns into waste and suggested an alternative framing of a CE where products and components become obsolete rather than waste, thus, reflecting that this is a state that can be resisted, postponed and reversed (den Hollander et al., 2017). Some scholars have criticised the CE for being a utopian approach (Cullen, 2017; Schröder et al., 2019), but in the context of design, it draws attention to the question 'how can designers generate truly sustainable or circular innovations if the current methods only lead them to optimise what is already there?' (den Hollander, Bakker, and Hultink 2017, p. 518).

The CE poses specific challenges for designers such as adopting a deeper understanding of materials (De los Rios et al., 2017), thinking in terms of multiple lifecycles (Franconi, 2020; Mestre & Cooper, 2017), concurrently developing the design of products and business models (Sumter et al., 2018), assuming a systemic view towards resources and their lifecycles (Ghisellini et al., 2016) and anticipating the existence of an alternative economy (Andrews, 2015). According to Den Hollander, design briefs in the CE will look entirely different to those in the current linear economy, as the context of a CE requires designers to consider multiple use cycles by multiple users and the entire product lifetime (den Hollander, 2018).

Aside from the technical or function-oriented challenges, it is likely that the aforementioned cultural barriers to a CE (such as the limited willingness to collaborate across value chains and hesitant company cultures; Kirchherr et al. 2018) will also appear as specific challenges in design processes. To address such challenges at the design stage, designers will have to shift their focus from being object creators to solution providers (Moreno et al., 2016) and develop trans-disciplinary skills and understanding (Charnley et al., 2011).

The need for systems thinking in design practice and education has also been highlighted as crucial for a CE by various scholars (De los Rios et al., 2017; Moreno et al., 2016; Whalen, Berlin, Ekberg, Barletta, & Hammersberg, 2018). Systems thinking is a widely studied subject in business (Murray et al., 2017) and design literature (e.g., see Charnley, Lemon, and Evans 2011)t. Yet, there has been little research investigating how and whether such approaches are applied and adopted in design practice. Charnley pointed out that 'designers have been provided with little guidance as to how these techniques should be implemented efficiently within an operational and substantially complex design process' (p.157). In sum, it appears that the CE poses specific challenges for the field of design that require specific knowledge, strategies and methods.

2.4 Design for a circular economy

2.4.1 Different scales of implementation

One can consider the CE to act on different scales of implementation. The guiding taxonomy of the micro level (products, components), meso level (buildings and eco-industrial parks) and macro level (cities, built environment; Ghisellini, Cialani, and Ulgiati 2016; Kirchherr, Reike,

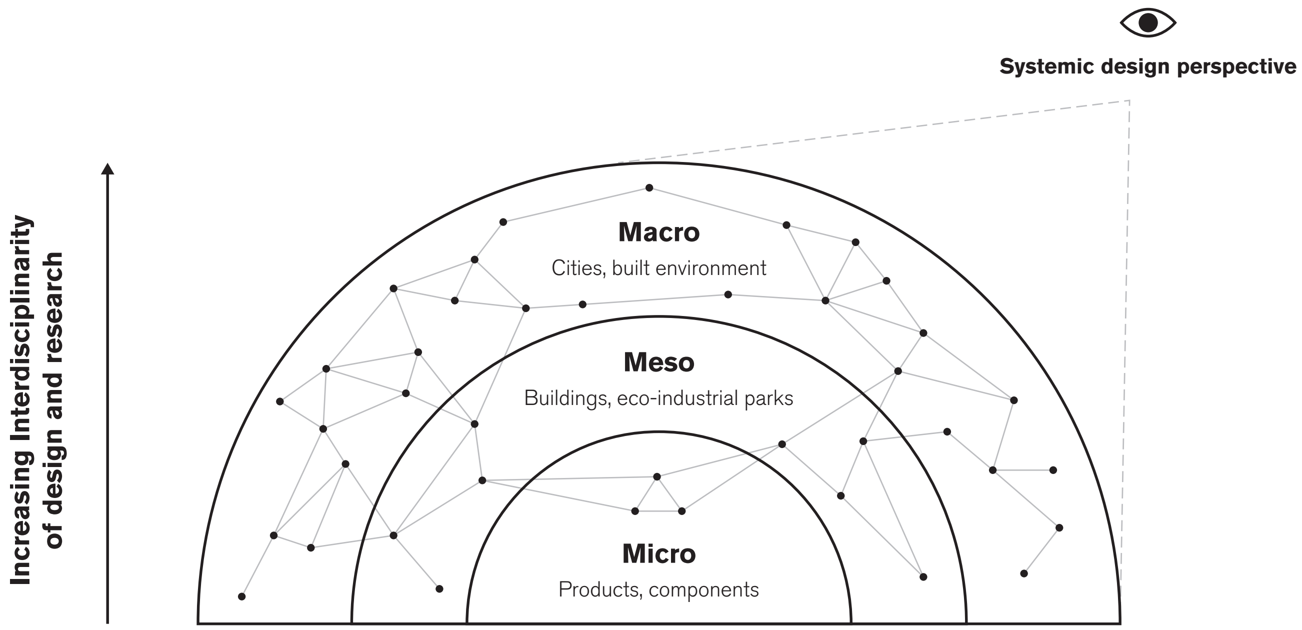

Figure 2. The CE requires designers to assume a systemic design perspective and consider the interaction between multiple scales of implementation. The scales are connected and expand in terms of the complexity and interdisciplinarity of the design challenges, hence, the lines separating the scales will and need to become increasingly blurred to support a CE.

and Hekkert 2017a; Pomponi and Moncaster 2017) provides a structured and helpful classification for distinguishing the different scales and contexts in which CE-related design activities exist. As previously mentioned, in attempting to implement a CE it is vital to adapt a systemic view towards resources and their lifecycles (Ghisellini et al., 2016; Iacovidou et al., 2017; Reike et al., 2018) and monitor CE progress from a systemic perspective (Pauliuk, 2018). The integration of such a systemic view into design methods and tools and across design practice is, correspondingly, of equal importance.

The CE is a tremendous challenge that extends beyond boundaries of scale and discipline. As illustrated in Figure 2, systemic design and interdisciplinary approaches are crucial to enabling designers to 'zoom out' and consider the interactions between different scales of implementation (e.g. micro, meso, macro). After all, designing products that are circular hinges on the design of entire systems that are circular, which are dependent on complex value chains and networks with numerous actors. Figure 2 also shows that the different implementation scales are 'connected' and expand in complexity; in the context of a CE, the lines that separate these scales become increasingly blurred.

As an example, consider the development of an electronic scooter-sharing system, a holistic design approach focusing on circularity would not only consider the micro scale (the physical design of the scooter) but also the interaction with the built environment (e.g., establishing physical facilities that would enable maintenance and repair activities), digital services (e.g., that could facilitate the logistical process of such maintenance and repair activities) and the actors in the value- and supply-chains who are required for such a system to function. In sum, circularity (or the qualification of 'circular') should be understood as the property of a 'system' (Konietzko, Bocken, & Hultink, 2020b), rather than the property of an individual product, building or service.

There are design frameworks and methods that facilitate a systemic approach and integrate the interaction between different scales, such as the multi-level design model proposed by Joore and Brezet (Joore & Brezet, 2015), whole-systems design (Blizzard & Klotz, 2012; Charnley et al., 2011; A. I. Gaziulusoy & Brezet, 2015) and sustainable PSS (Ceschin, 2013; E. Manzini & Vezzoli, 2003; Vezzoli, Ceschin, Diehl, & Kohtala, 2015). Nogueira et al. suggested the use of eight capitals as innovation lenses for the CE (natural, financial, manufactured, digital, human, social, cultural, political) to promote systems thinking and capture the full scope of dynamics within a system and also proposed the design-led participatory approach of 'infrastructuring' to address multi-level contexts and find potential collaborations between actors (Nogueira, Ashton, & Teixeira, 2019; Nogueira, Ashton, Teixeira, Lyon, & Pereira, 2020).

However, thus far limited frameworks and methods have specifically considered the interaction between different implementation scales in the context of a CE. The remainder of this chapter further explores current research on design in the context of a CE, particularly on the micro- and meso-level scale and the existing methods and tools that support circular design.

2.4.2 Micro level - Circular design of products

Extensive research has been performed regarding design for a CE on the micro scale in the context of (consumer) products and building components. Moreno et al. (2016) developed a conceptual design framework for CE design strategies, based on the systematic analysis of various Design for Excellence (DfX) strategies. Bocken et al. (2016) presented a design framework that incorporates the terminology of slowing, closing and narrowing resource loops and provides an overview of product design and business model strategies that can be utilised to move to a CE. Slowing resource loops can be achieved by designing products in a way that extends their lifespans, for example, through design for repair and maintenance and design for (functional, emotional and aesthetic) durability (C. Bakker, Wang, Huisman, & Den Hollander, 2014; van Nes & Cramer, 2006). Closing resource loops refers to designing products so that the components and materials can be eventually reused and recycled. This can be achieved, for example, through design for disassembly (DfD; Go, Wahab, and Hishamuddin 2015). Narrowing resource loops refers mostly to product optimisation through the more efficient use of resources, for example, through avoiding over-design, dematerialisation and more intensive product use (Allwood, 2018; Allwood et al., 2011). Den Hollander (2018) developed the design methodology 'Design for Managing Obsolescence', which replaces the notion of products turning into waste at EoL with the alternative framing of obsolescence, which is a state that can be resisted, postponed and reversed through various design approaches. This methodology enables industrial designers to synchronise product designs and business models to maximise the potential for circularity. Some design approaches and frameworks focus more specifically on the perspective of the end-user to support the closing of resource loops (Poppelaars, Bakker, & van Engelen, 2020; Selvefors et al., 2019; Wastling et al., 2018) and on multiple lifecycles (Franconi, 2020; Mestre & Cooper, 2017). Furthermore, there are also various tools that have been introduced by practitioners such as the Circular Design Guide (Ellen MacArthur Foundation & IDEO, 2017) and grey literature to support design for a CE (Bakker et al., 2015; Haffmans et al., 2018).

Previous research has also discussed the role of PSS solutions and digital technologies as enablers for a CE and CE-oriented design. As previously discussed, PSS can foster longer relationships with customers and incentivise extensions of product lifetimes, environmental impact reduction and enable social wellbeing and economic prosperity (Vezzoli et al., 2015). Furthermore, smart technologies and IoT are expected to turn physical products into feedback-rich systems that can collect data during product use and can improve the connection between producers and designers and the lifetimes of products (Alcayaga, Wiener, & Hansen, 2019). Feedback data could also be utilised by designers to analyse how products are used and discarded, improve the technical design and foster product attachment and trust (Ingemarsdotter, Jamsin, Kortuem, & Balkenende, 2019).

2.4.3 Meso level - Circular design of buildings

On the meso scale, the implementation of the CE and CE-related design is frequently discussed in the context of buildings and the construction sector. One way of moving towards a circular built environment is to extend the service life of buildings through various design approaches such as adaptive design and reuse, DfD and design for repair and remanufacturing (Benachio, Freitas, & Tavares, 2020; European Commission, 2020b; Hopkinson, De Angelis, & Zils, 2020; Joensuu, Edelman, & Saari, 2020; Minunno et al., 2020; Ness & Xing, 2017; Pomponi, De Wolf, & Moncaster, 2018). There have also been discussions concerning the greater adoption of renewable materials for structural components in buildings, such as mass timber products (Campbell, 2018). PSS practices are discussed as relevant to the context of the built environment, as these systems could help facilitate maintenance activities and service life extensions of buildings through adaptive reuse and the more efficient use of buildings (e.g., sharing economy principles), which could decrease resource consumption and limit the growth of the building stock (Fargnoli et al., 2019; Joensuu et al., 2020). Digital technologies such as material passports (digital sets of data describing materials and components in products and systems) and digital twins (virtual clones of systems or subsystems e.g., products or buildings) are also considered to be enablers of circular design, as such solutions can provide information about the present use, recovery and reuse of materials and components and inform designers and decision makers about the technical and spatial reversibility of design artefacts (Debacker et al., 2017). However, CE practices in the built environment to date have primarily focused on waste management and the minimisation and reuse of construction and demolition waste (Joensuu et al., 2020; Munaro, Tavares, & Bragança, 2020).

Cambier, Galle and Temmerman (2020) presented an overview of available design tools that are relevant for circular building over different stages of the design process and divided them into the following subcategories: Design principle tools, material flow analysis tools, life cycle assessment tools, material and product labels, reused material platforms, material passport tools, life cycle cost tools and knowledge sharing platforms. The same research emphasises the need for practical insights (e.g., case examples and best practices of circular building) and finding ways of supporting collaborations between actors to better inform design choices by individual stakeholders. Cambier et al. also identified the need to investigate PSS solutions as a connecting

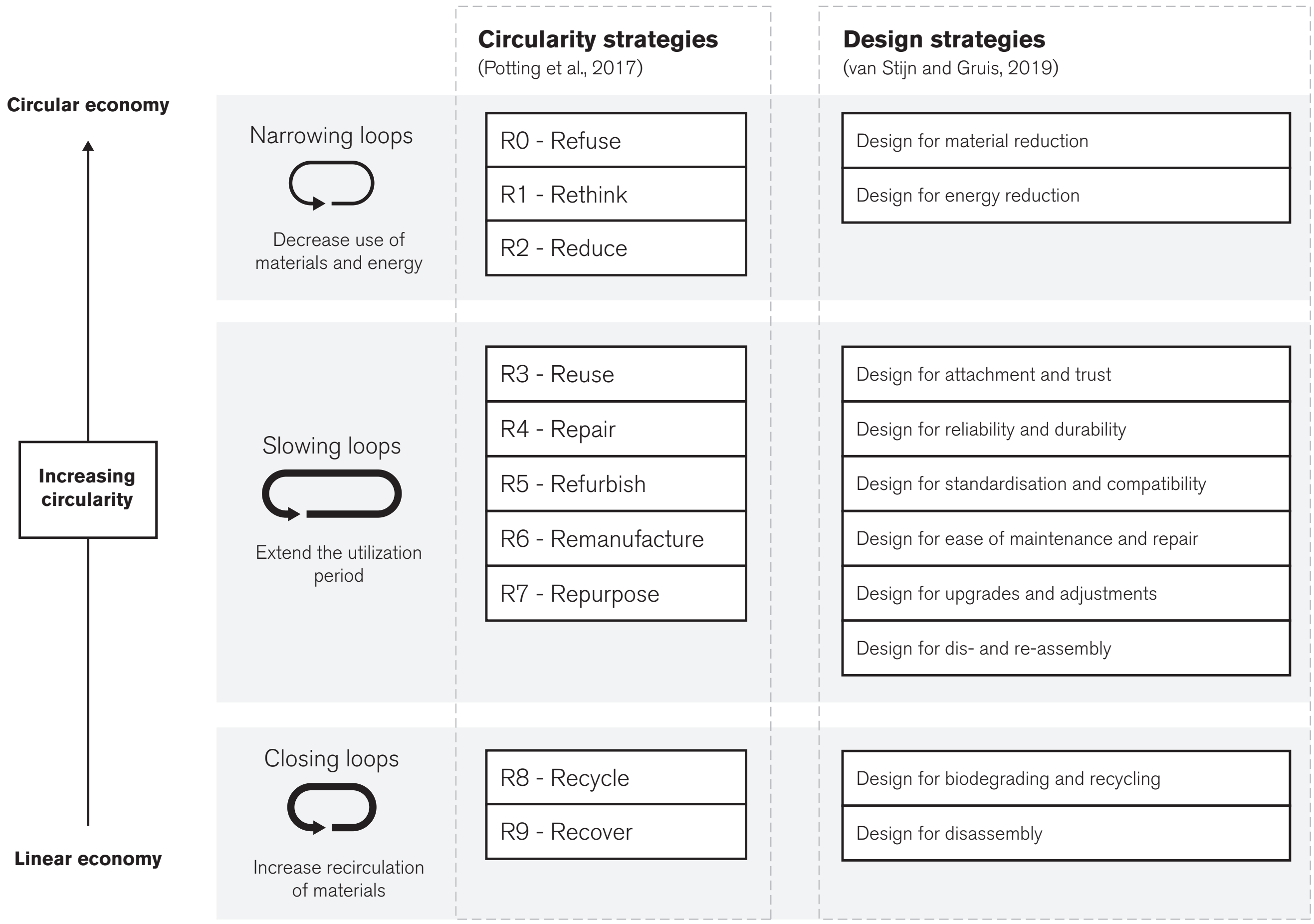

Figure 3. An overview of the generic circular strategies for value chains and design strategies to support the different resource cycles of narrowing, slowing and closing loops.

factor between design, business strategies and the lifecycle management of assets; these solutions could also build on the changing role of the designer from short-term involvement to long-term involvement with buildings. Pomponi and Moncaster (2017) described a research framework for the CE in the built environment spanning six dimensions (governmental, economic, environmental, behavioural, societal and technological), which encourages an interdisciplinary approach towards research and emphasises that the greatest challenge for the CE is related to social and behavioural factors.

It is crucial to support designers with assessment methods that identify relevant criteria and metrics for circularity and can help 'quantify' the extent to which design proposals support circularity to make better informed design decisions. However, another important question is how design synthesis and conceptualisation can be supported in the context of a CE in a way that ensures a holistic and systemic design approach. Van Stijn and Gruis (2019) analysed 36 existing circular design frameworks, established a comprehensive overview of circular design strategies and developed a design tool that supports an integral approach for circular design proposals that simultaneously considers the combination of the physical design, circular business models and value chain interactions. The tool is meant for the design of circular building components; therefore, it is not restricted to the design of buildings and relevant for both the micro and meso scales.

Figure 3 shows a combined visual overview of the circularity strategies from the R9 model by Potting et al. (2017) and various design strategies provided by Van Stijn and Gruis, which are viable for the micro and meso scales, distributed amongst the different resource cycle categories by Bocken et al. (2016). Generally speaking, moving upwards in the circularity strategies indicates a higher level of circularity as this implies fewer natural resources are utilised and less environmental pressure is caused.

Based upon the investigated literature, it is apparent that in both the context of the micro and the meso scales, extensive research is taking place to develop appropriate knowledge, tools and methods to support design for a CE. Similar design strategies can be observed that facilitate the extension of lifetimes and the utilisation periods of products and buildings, such as DfD and design to facilitate repair and maintenance. At both levels, PSS and ongoing developments in digital technologies appear to be enablers for circular buildings and products and could eventually support designers in better understanding lifecycles and optimising them for circularity. From the literature, it is also apparent that thus far there have been few investigations examining design for a CE from the perspectives of the micro and meso scales and exploring the interplay between these scales.

2.5 The role of designers and architects in the circular economy

It is likely that the systemic shift of moving from a linear to a CE will have implications for the role of designers in the context of the built environment and consumer products. Rios et al. (2017) mentioned how product designers have to develop deep material knowledge, proficiency in service design and a richer understanding of social behaviour. Furthermore, the authors suggest different designer profiles or 'design personas' based on the business-market-technology context. Den Hollander (2018) highlighted that the role of industrial designers will change from a predominantly operational one to a more strategic business one, which will require further collaboration between designers and other disciplines such as marketing and further knowledge of business sciences. Sumter et al. (2020, 2021) described specific CE-relevant skills and competencies for industrial designers such as anticipating the future use cycles of products, assessing environmental impacts, collaborating more extensively with stakeholders and CE storytelling, that is, being able to engage and convince internal and external stakeholders of the meaning and value of the CE.

Related to the role of the architectural designer, Galle et al. (2015) discussed the need to change from the short-term involvements of the designer to long-term engagements to encourage lifecycle thinking and the well-considered management of buildings. Kozminska (2019) argued that the circular design process differs substantially from the standard design approach based upon the investigation of a set of architectural case studies. Accordingly, the design process requires interdisciplinary collaboration and should encompass the lifecycle of materials to define future methods of maintenance, disassembly and the reuse of materials. Finally, Kanters (2020) discussed how architects can play a pivotal role in the transition to a CE by linking different actors (e.g., client, contractor, other consultants, engineers) but will need to develop leadership skills to fulfil this role. In addition, they will need to develop the ability to work with flexibility in the design process and acquire deeper material and construction knowledge.

2.6 Collaboration and participatory design in the circular economy

There is a growing consensus that collaboration is crucial to enabling the transition to a CE (Blomsma, Pigosso, & McAloone, 2019; Brown et al., 2021a; Brown, Bocken, & Balkenende, 2020; Geissdoerfer et al., 2018; Ghisellini et al., 2016; Hofmann & Jaeger-Erben, 2020; Leising, Quist, & Bocken, 2018). Accordingly, the transition to a CE will succeed not through actors advancing their individual interests but rather through establishing new ways of working, new business partners, new roles of existing partners and new kinds of collaborations between stakeholders (Aminoff et al., 2016). According to Kirchherr et al. (2018), based upon the European context, it is precisely the lack of willingness within value chains to collaborate that forms one of the major barriers to a CE. Nogueira, Ashton and Teixeira (2019) noted that the processes and compositions of partnerships, the importance of relationships, and the creation of networks and formation of new alliances have only been explored to a limited extent and present challenges that go beyond current CE practices, which mainly focus on material flows and product life cycle extensions.

Challenges regarding collaboration have also been discussed in the context of the built environment, where the lack of a collaborative and holistic approach within the supply chain and the 'silo' approach towards design, construction, facility management and EoL activities are considered to be the key challenges (Adams et al., 2017; Hart et al., 2019).

Some scholars have also discussed the importance of collaboration in the design process in the context of a CE and how this might affect the role of designers. Pedersen and Clausen (2019) discussed the role of designers as 'orchestrators' who utilise co-design methods and can stage negotiations between actors and (re)align their values through designing prototypes as 'knowledge objects'. In this case, the designer acts as the connector and facilitator (Ezio Manzini, 2009) who stages connections between stakeholders and creates the space for circular innovation. Other research has discussed the collaboration between designers and waste management in the effort to connect and close resource loops (Ordoñez & Rahe, 2013). Sumter et al. (2020, 2021) emphasised the importance of interpersonal competency amongst industrial designers and defined 'Circular Economy Collaboration' as a specific competency, described as the capability to 'facilitate and engage collaborations across value networks in order to create circular product-service systems and stimulate the transition toward a circular economy'.

Some tools have also been developed to stimulate CE collaboration such as the tool by Leising, Quist and Bocken (2018) that addresses supply chain collaboration from the design stage to the EoL of buildings and the circular collaboration canvas that helps to identify partners and perceived values and translate these into the design of circular propositions (Brown et al., 2021b). Overall, it is apparent that the success of design initiatives focusing on establishing circularity relies to a great extent on the collaboration between actors (and the willingness to collaborate) and a well thought-out design process that considers and establishes well-functioning and long-lasting collaborative networks.

This raises the question of the role of designers in facilitating connections and collaboration between stakeholders and how this is approached within the design process. In addition, it raises the crucial issue of how collaborations can be maintained and enhanced during and after the lifecycles of products, buildings, components and materials. As crucial CE-related design challenges may appear once products are in use (Sumter et al., 2018), design and optimisation that address the end of use cycles and EoL scenarios become ever more important.

To date, there is little knowledge concerning how collaboration in support of a CE is approached in the design process and to what extent designers can influence collaboration. Furthermore, the collaboration and interaction between different design disciplines should not be overlooked. It is likely that the transition to a CE will also require more extensive collaborations between different disciplines of design and different types of designers, be they industrial designers, service designers, strategic designers, or architects. The German Bauhaus school that was founded in 1918 is famous for addressing complex societal challenges through the synthesis of the creative disciplines of art, architecture and design. The Bauhaus showed how diversified thinking, broad disciplines and skilled experimentation and the urgency of the societal challenges can lead to fruitful progress. Perhaps it is not surprising that now, a little over a century later, the European Commission has announced the formation of 'a new European Bauhaus', 'a co-creation space where architects, artists, students, engineers, designers work together' to help Europe move toward a CE (Bason et al., 2020; European Commission, 2020c).

Finally, participatory design approaches such as co-creation and co-design are also relevant in the context of the CE as they promote the collaboration between and inclusiveness and representation of various actors and perspectives in the design process including the users, clients, experts, value- and supply-chain actors and other stakeholders. The practice of collective creativity and user participation in the product development process (i.e., participatory design) has its roots in Scandinavia and dates back to the 1970s (Sanders & Stappers, 2008). While co-creation is rather broad and can refer to any act of collective creativity, co-design (in this thesis) is perceived more specifically as the act of collective creativity between designers and people who are not trained in design throughout design development processes.

Participatory design through time has developed from traditionally being concerned with involving users in evaluative research (i.e., testing existing products or prototypes) to taking part in generative research and techniques that inform designers in early phases of the design process (Visser et al., 2005). In the context of the CE, participatory design is, on one hand, crucial for gaining a better understanding of the way people might engage, interact and accept circular and service-based solutions that are often 'accessed' rather than 'owned'(Poppelaars, Bakker, & van Engelen, 2018). On the other hand, in large systemic transformations such as the transition to a CE, neither agency nor power is distributed evenly among stakeholders. Therefore, participatory design approaches can have a political and democratic function and enable the articulation of aligned and conflicting perspectives, generate diverse values on how change should take place collaboratively and demonstrate the diversity of viable alternative futures for all (A. İ. Gaziulusoy & Ryan, 2017).

Luck (2007) investigated and compared experienced expert architects and architectural graduates and found that the effectiveness of participatory design to some degree is reliant on the expertise of the facilitator, and the skills to facilitate participatory design workshops are learned over time and through experience in practice. Ezio Manzini (2017) discussed how the role of the design expert and facilitator in co-design processes is often reduced to 'post-it design' (i.e., taking a step back and asking other actors to stick their opinions and wishes on a wall that are then collected and synthesised following a rather formalised process) and emphasised instead that design expert facilitators should be simultaneously critical, creative and dialogic and feed conversations with visions and ideas, listen to feedback from the actors and the environment and then introduce more mature proposals into the conversation.

Based upon the investigated literature, it is apparent that participatory design and co-design methods have not been extensively investigated in the context of CE collaboration. In this regard, Blomsma et al. (2019) noted that stakeholder management is a common theme in CE research, but little research has focused on investigating methods for the co-design of CE value chains in terms of how to select strategic partners, when to engage them and in what capacity.

3. Methods

3.1 Research design

The research included in this thesis is positioned within design research, which can be defined as 'the study of how designers work and think, the establishment of appropriate structures for the design process, the development and application of new design methods, techniques and procedures, and the reflection on the nature and extent of design knowledge and its application to design problems' (Cross, 1984; Kuijer, 2014). To satisfy the aforementioned aims, the thesis adopted an explorative and practice-based approach that builds on the three empirical studies that are outlined in Figure 4.

Given the newness of and limited empirical investigation into design for a CE, the research adopted an overall qualitative approach to support the explorative nature of the research. The qualitative inquiry was performed primarily in the form of semi-structured interviews. A qualitative approach supports an inquiry that considers the complexity of real-world cases and gains a deeper understanding of how people in real-world situations 'make sense' of their environment and themselves through a primarily inductive process (Groat & Wang, 2002). Though not exclusively inductive, qualitative research tends to emphasise the holistic exploration of complex situations and environments in which the testing and deduction of sequenced or causal relations are unlikely. As human behaviour cannot be understood without reference to the meanings and purposes attached by human actors to their activities (Guba & Lincoln, 1994), it is precisely here that qualitative data can provide rich insights into the 'how' and 'why' questions related to the interpretations and operationalisations of the CE across design practice.

Unlike scientists who solve problems through analysis and are dependent on 'problem-focused' strategies to advance their contributions, designers solve problems by synthesis and rely on 'solution-focused' strategies to intervene in reality (Cross, 1982). Therefore, in addition to the qualitative inquiry that investigates the current state of the art in CE implementation, the research also utilises a Research through Design (RtD) approach as a design inquiry to a 'wicked problem' (Zimmerman, Stolterman, & Forlizzi, 2010) to explore what potential futures might

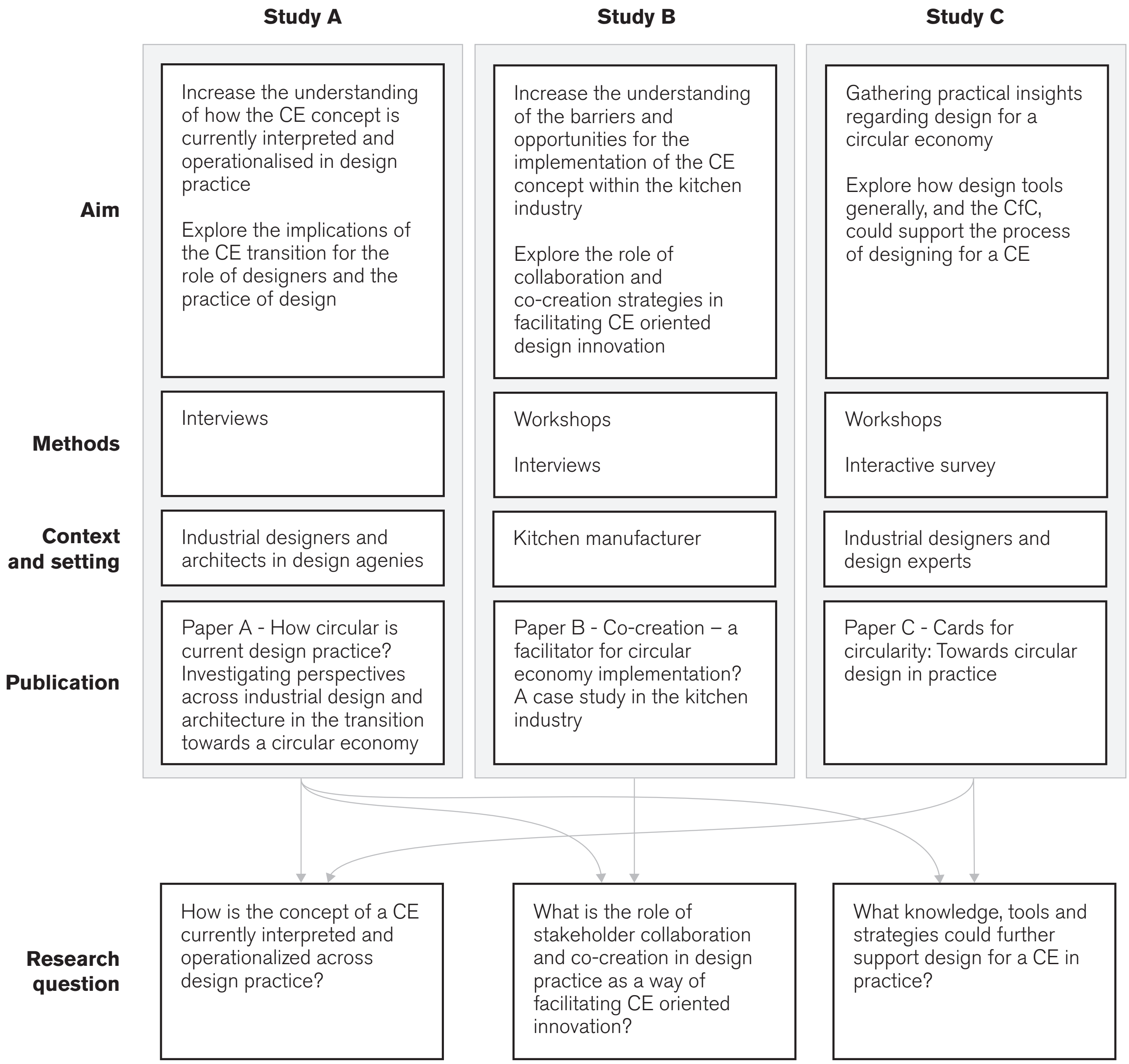

Figure 4. Overview of the three studies included in this thesis and their relation to the research questions.

look like and how CE implementation can be supported through the formulation of appropriate guidelines, tools and methods.

In RtD, the design action itself is essential to knowledge generation and carried out by the designer-researcher (Stappers, Visser & Keller, 2014). This approach should not be confused with Research into Design (relating to the human activity of designing) and Research for Design (relating to research that aims to advance the practice of design; Frayling 1993).

As can be seen in Figure 5, the goal of the designed artefact in this case is to gain knowledge by exploring a phenomenon (phenomenon-driven input), even if the designed artefact might result in a product as a side-effect (Horvath, 2007). This was the case in Study C, where knowledge was generated about a phenomenon (designing for a CE) through the use of a prototype (the card-based design tool).

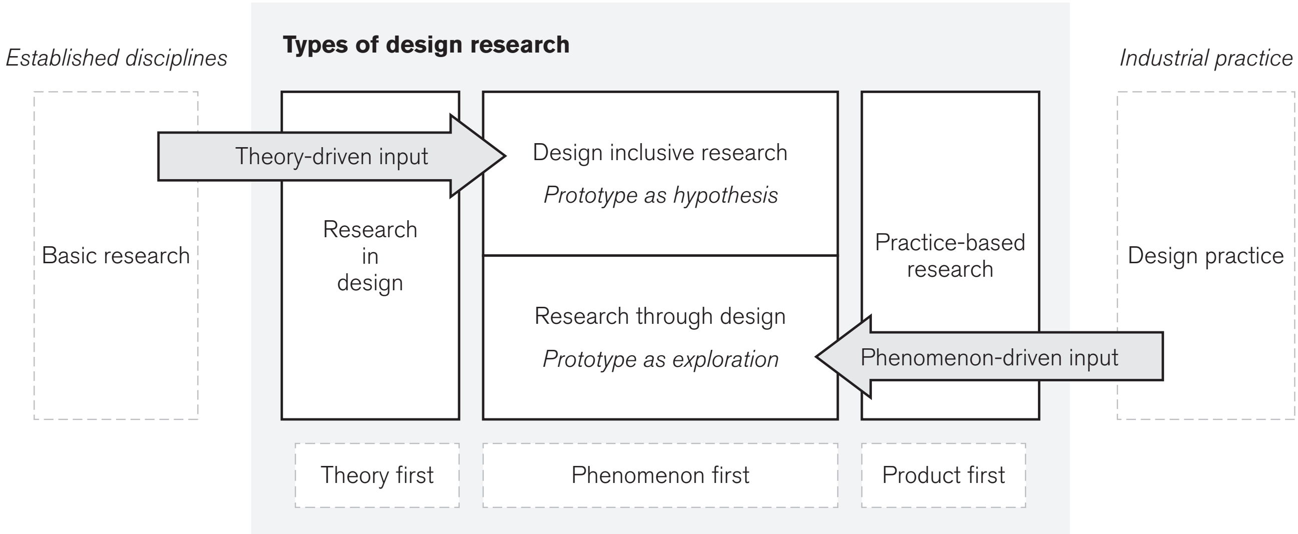

Figure 5. Types of design research (adapted from Stappers, Visser & Keller 2014 and Horvath 2007).

While the interviews included in Study A are useful for gathering explicit knowledge, Study B and Study C featured generative sessions in the form of design workshops to establish a deeper understanding and gather tacit (which cannot be verbally communicated) and latent knowledge (which refers to the thoughts and ideas of users on what has not yet been experienced but on which they may have an opinion based on past experiences) (Sanders and Stappers 2012).

3.2 Study A

The aim of Study A (resulting in Paper A) was to generate a better understanding of how design practitioners within the disciplines of architecture and industrial design interpret and implement the concept of a CE in practice. Therefore, insights and case-based evidence were gathered from design practitioners who participated in design projects in which circularity was a particular focus or theme. The data in this empirical study was collected mainly through semi-structured interviews as this 1) allows for the exploration of certain topics in depth while maintaining an openness towards more detailed responses and 2) enables the participants' terminology and judgements to be learned and captures the complexity of their individual perceptions and experiences (Patton, 2002).

Between January 2020 and July 2020, a total of 12 interviews were conducted, which lasted between 60 and 96 minutes. To support the interviews, an interview guide was developed that covered general, project- and design- specific questions (see appended Paper A). The interviews were conducted in English; face-to-face (n = 2) and through the digital communication tools Zoom (n = 9) and Skype (n = 1). The interviews were digitally recorded with the permission of the participants and transcribed afterwards. The interview data was complemented with written notes and case-specific information gathered from the companies' websites. Interview 2 featured two participants who had collaborated on discussed projects.

The focus was to select participants within the disciplines of architecture and industrial design

Table 1. Overview of interviews and participants. Company size (employees): Micro (1-9), Small (10-49), Medium (50-249) and Large (250+). Role description: A (Architects) and ID (Industrial Designers).

#	Role	Organisation type	Company size	Location	Exp. (years)	Rationale for involvement
1	A	Architectural firm	Large	Sweden	10	Development manager circularity in firm's research lab
2	A	Architectural firm	Large	Sweden	14	Interior architect responsible for public building with circular interior. Case nominated for international design award
	A				34	Developed methods for circular interior projects in research project focusing on circular furniture flows
3	A	Architectural firm	Medium	Denmark	11	Head of research consultancy specializing in circular design
4	A	Architectural firm	Medium	Denmark	8	Part of project group in large-scale architectural project researching circular construction featuring 60+ value chain actors
5	A	Architectural firm	Micro	The Netherlands	12	Founder of firm with core focus on circular architecture
6	A	Design studio	Micro	Sweden	17	Founder of design studio with core focus on circular interiors
7	A	Circular start-up	Micro	The Netherlands	9	Founder of a start-up specializing in designing circular furniture and prefabricated products for construction
8	ID	Design company	Large	United States	26	Executive design director involved in the development of a circular design tool. Public speaker on circular design
9	ID	Design consultancy	Medium	Sweden	5	Involved in project developing a circular product and business model. Consultancy with sustainability/circularity as core service
10	ID	Design consultancy	Small	The Netherlands	33	Partner in consultancy with sustainable design/circularity as focus area
11	ID	Design studio	Micro	Sweden	33	Founder of studio with core focus on sustainability and upcycling. Nominated for several awards for upcycled design. Public speaker on upcycling
12	ID	Design studio	Micro	Sweden	16	Designed furniture with focus on circularity for international furniture brand. Won several internationally recognized design awards

who work in a design consultancy setting to acquire rich and representative data drawing on experiences from multiple cases. The participants were selected based on the following criteria: (1) the participant has been involved in design projects with an explicit focus on circularity, and/or (2) the participant is part of an organisation with a particular focus on designing for a CE, (3) a balance of industrial designers and architects is represented and (4) companies of different scale are included. The scope of this study was limited to the EU, where design plays a central role in

CE policies (e.g., see European Commission 2020a) and the interview participants were situated in Sweden, Denmark, the Netherlands and the United States (one participant is stationed in the US but is active in a European context and is originally from Germany). See Table 1 for a detailed overview of the participants including the size, type and location of the affiliated organisations, and the years of experience and rationale for the involvement of the participants.

The analysis of the interviews followed an inductive approach to enable the uncovering of new concepts, as fieldwork that is not constrained by predetermined categories of analysis contributes to the depth, openness and details of a qualitative inquiry (Patton, 2002). The data analysis was structured according to the methodology developed by Gioia, Corley, and Hamilton (2013), which contributed to the qualitative rigour of the study. A three-tiered iterative coding process was performed that firstly searched for emerging themes defined as first-order themes, and secondly searched for relationships between first-order codes to establish second-order themes, which were then assembled into four aggregate dimensions (see appended Paper A for a detailed coding scheme).

3.3 Study B

The aim of study B (resulting in Paper B) was twofold: (1) to increase the understanding of the barriers to and opportunities for the implementation of the CE concept within the kitchen industry and (2) to explore the role of co-creation strategies in establishing CE awareness amongst industrial actors and facilitating CE-oriented innovation. The focus on the kitchen industry was due to the fact that the study was conducted in the context of the Circular Kitchen research project, which explored the potential of the CE in the kitchen industry and sought to generate knowledge for kitchen design solutions and business models based on the concept of a circular economy.

To support this aim, the study was divided into two parts. First, three co-creation workshops were conducted together with a medium-sized Swedish kitchen manufacturer. Following this, interviews were organised with different employees of the company to evaluate the experiences of the co-creative workshops and the attitudes and interpretations towards the CE and to identify potential barriers to and opportunities for circularity in the products and business model of the manufacturer.

The three co-creation workshops were organised with the purpose of (1) developing an understanding of the CE concept within the company, (2) exploring the potential and feasibility for circularity in the kitchen industry and for the involved kitchen manufacturer and (3) co-creating concepts for a circular kitchen and business model with the ultimate aim of developing a circular kitchen prototype. The workshops, lasting between half a day and a full day, took place at the company and consisted of a team of up to five researchers and up to ten representatives from different departments of the company such as product development, marketing, management and IT and customer service (see Table 2 for a detailed overview of the workshops). Five semi-structured interviews were conducted with company representatives who had participated actively in at least one of the workshops. The interviews were carried out face-to-face (n = 3) and by email (n = 2). The interviews inquired about the participants' experiences of the workshops, their interpretations

Table 2. Overview of the co-creation workshops.

#	Role	Participants	Purpose	Activities	Outputs
1	2 Jul 2018	CEO (Owner) Product range manager Product coordinator Product manager Constructors (2) Concept marketeer Researchers (5)	Project introduction Relationship building Market analysis Stakeholder mapping Idea generation	Company presentation Factory tour SWOT analysis Stakeholder analysis Innovation workshop	Stakeholder map Company and market analysis Ideas for promoting circularity in kitchens
2	11 Sept 2018	CEO (Owner) Product coordinator Product manager Constructors (2) Researchers (5)	Evaluate concepts Identify circular business model opportunities Identify relevant stakeholders	Concept presentation Concept evaluation Circular business model canvas workshop Stakeholder mapping (continuation)	Concept evaluation and selection Ideas for circular business model
3	12 Oct 2018	CEO (Owner) Product coordinator Marketing manager IT manager Customer service manager Researchers (5)	Agree on circular goal/ vision for project/company Further development of selected concept	Define circular vision project and company Discussion concept selection Evaluation opportunities/ challenges for selected concept	Circular vision 2022/2030 Concept evaluation Prototype plan

and attitudes towards the CE and the vision of the project. Material from the workshops and a diagram of the CE concept by the Ellen MacArthur Foundation was used to guide the interviews.

The data collected consisted of audio recordings (with the permission of the participants), photographs, written notes, observations and material resulting from the workshops. The qualitative content analysis focused on revealing how interpretations and attitudes towards the CE concept throughout the workshops were formed and how ideas were developed. We assumed a critical perspective towards the ways in which roles and collaboration influenced the outputs of the workshops. The interview transcripts were coded and analysed following an inductive coding process utilising the software NVivo (release 1.2).

3.4 Study C

Study C (resulting in Paper C) describes the development of the card-based circular design tool Cards for Circularity (CfC), which was utilised in a workshop with design practitioners with the aim of (1) gathering practical insights into design for a circular economy and (2) exploring how design tools generally, and the CfC in particular, could support the process of designing for a CE. This study followed a RtD approach, in which the design action itself is essential to knowledge generation and carried out by the designer-researcher (Stappers et al., 2014). The study was conducted in several steps. First, existing circular design methods were reviewed, and a card-based circular design tool was developed. Next, a half-day workshop (approximately five hours) was organised with 12 design experts (10 practitioners and two researchers) in which an interactive survey was conducted with the participants to evaluate current knowledge and practices regarding circular design, and a design workshop was organised that utilised the CfC.

Card-based tools have been reviewed as being beneficial for ideation within design processes as they provide summarised, semi-structured information that bridges the gap between unstructured tools without content such as post-it notes and detailed structured information such as instruction manuals (Roy & Warren, 2019). As a theoretical foundation for the design of the cards, the circular building components (CBC) generator was selected, which is a design tool for circular building components suitable for multiple implementation scales. It is based on a systematic literature review and the analysis of 36 existing circular design frameworks (van Stijn & Gruis, 2019). The CBC generator includes all the relevant parameters that should be considered (e.g., materials, lifecycle, design strategy, type of financial arrangement) to support the systemic synthesis of an integrally cohesive circular design solution.

The CfC tool consists of a variety of cards featuring design parameters that relate to choices designers need to make in a circular design, for example, choices related to applied circular design strategies, materials and lifecycles. The cards consist of three colours to distinguish the technical model (relating to the physical design of the artefact), the industrial model (relating to value chain interactions) and the business model (marketing and finance aspects). The cards are intended for use not only in the ideation phase but in different contexts and stages of the design process (See appended Paper C for a visual representation of the cards).

The workshop began with an interactive survey, with the aim of evaluating the participants' knowledge, experiences and practices related to designing for a CE and finding potential challenges that could be addressed through design tools. The interactive polling tool Mentimeter was used to ask the audience a range of questions, which were focused on knowledge and practices related to the CE and challenges to promoting circularity in design practice and business. Each question was followed by a short group discussion in which the participants could verbalise further thoughts.

The interactive survey was then followed by a design workshop (that lasted approximately 45 minutes) in which the participants were divided into three groups and tasked with designing ideas and concepts for kitchen furniture and appliances based on the CE concept by utilising the CfC. Each group was provided with a reduced set of cards (48 cards) from the technical model that represented different design options for the following parameters: material, lifespan, lifecycles and circular design strategies. The options for the business and industrial models were

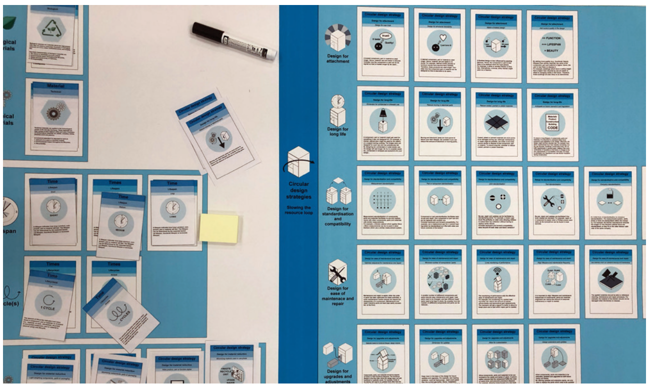

Figure 6. One group during the workshop (left) and depiction of the map with cards (right).

excluded from the workshop because of time limitations. Each group used the same cards but was provided with a slightly different context, namely developing ideas for rental or privately owned apartments. The groups were invited to different tables for the design task, on which the cards were pre-configured on a map with different categories to provide structure and a means of navigating (See Figure 6). The data gathered and analysed during this study was survey responses, audio records, written notes and observations. The audio records were transcribed and analysed by using the software NVivo 12. Through an emergent coding process, a list of first-order and, consecutively, second-order codes were assembled related to attitudes, challenges and enablers of circular design in practice.

4. Findings

4.1 Study A - Circular design practices across industrial design and architecture

This chapter provides a summary of the findings of Study A, in which interviews were conducted with design practitioners within the disciplines of architecture and industrial design. These revealed various perspectives on designing for a CE related to (1) the circular design process, (2) the effects of the CE on design agencies, (3) the changing role of the designer, and (4) the external factors affecting circular design in practice. For a comprehensive overview of the findings, see appended Paper A.

4.1.1 The circular design process

The findings of Study A indicated that in both the contexts of industrial design and architecture, the overall design process tends to become more complex in design projects with circularity as a focal point, in the sense that it extends the lengths, costs and overall scope of the projects. The study participants mentioned how such CE-oriented projects require additional and extensive knowledge of materials, biology, ecology, environmental impact assessments, stakeholder management and a deep understanding of the structure of business models and supply and value chains. The objective of closing resource loops typically means that more stakeholders need to be involved in the design process from the beginning, whose individual demands need to be managed. A more extensive initial research phase is needed in design projects to create a deep understanding of the supply and value chains involved and grasp the entire system related to the project. These factors make for a design process that is generally perceived as ‘longer’ due to the aforementioned expansiveness and an increased number of iterations and feedback loops.

Study A also indicated that the design process in the context of the CE is becoming increasingly data-oriented due to more extensive efforts in the assessment of environmental impacts and the fact that digital technologies will, to an increasing extent, turn physical artefacts into ‘living’ assets that can provide feedback. This feedback was considered to be crucial by both architects and industrial designers for better understanding the lifecycles of products and buildings and finding interventions that might enable lifetime extensions and the recirculation of resources. Furthermore, the participants mentioned data analytics as a design tool, and the use of material passports and digital twins to embed information into products and buildings relating to materials, components, structural integrity and intended disassembly steps (increasing the feasibility of DfD strategies).

Based upon the interviewees with the architects in Study A, it is apparent that CE practices in the built environment to date have primarily focused on the reuse of existing (waste) materials for the design of new buildings and structures, thus, limiting the use of virgin materials and reducing overall environmental footprints. This process requires a level of flexibility and equivocality in the design process as it is uncertain what building waste, secondary raw materials and spare building components will be identified, mapped and collected during the 'inventory' process.

Design strategies for lifetime extensions (e.g., how to enable repair and maintenance) and the future reuse of components and materials (e.g., DfD) were discussed to a lesser extent by the participants. Circularity in the built environment appeared to be strongly associated with the reuse of waste materials (especially from the market demand side), which was illustrated by one of the discussed design cases of a bike shed that was no longer described as 'circular' after deviating from the initial plan of reusing waste materials and opting instead for the use of renewable materials and a DfD approach. Various reasons were highlighted for the current focus on reusing materials within the architectural design process; it is considered an easy way to engage with circularity, it can reduce costs and it is better for the environment to reuse old materials rather than to use new ones.

The interviews with the industrial designers revealed that the product design approach in the context of a CE becomes increasingly system- and service-centred rather than object-centred. The participants mentioned that circular product design relies on the design of systems; these include the design of a product, a business model and services to capture value from and incentivise product lifetime extensions and resource recovery.

Concretely described strategies utilised in the design process were upcycling and making products modular and parts exchangeable to (1) enable recycle, refurbish and repair practices; (2) promote take-back schemes; and (3) adapt to the demands and preferences of different users.

4.1.2 Effects of the circular economy on design agencies

Study A found that the CE discourse has had several effects on the everyday operations of the design agencies involved in the study. One effect has been the assembly of dedicated internal teams or research 'labs' that are specifically focused on designing for a CE in the larger organisations in the study. According to the participants, this enables agencies to investigate CE-related knowledge gaps and explore ideas for which clients are not willing to pay. In addition, when knowledge gaps are encountered, external experts may be included in the design process (e.g., biologists to enhance the biodiversity of a building design); if knowledge gaps are structural or pivotal to design choices (e.g., LCA assessment), additional knowledge may be deliberately internalised.

Another effect has been that agencies are increasingly questioning to what extent the traditional design consultancy business model supports agencies in engaging with circularity and the ecological challenges in product and building design. The study participants described how design still most often consists of a temporary effort and engagement between the designer and client, which does not encourage the long-term engagement of the designer with the lifecycles of designed artefacts. In some fields, such as furniture design, designers are frequently rewarded based on the number of pieces sold (in the form of royalties), which essentially does not stimulate designers to think in the long term and devise ways to extend the lifetime of furniture (e.g., through repair and reuse practices).

Both the interviewed architects and industrial designers stressed the importance of extended partnerships and alternative revenue models; for example, an alternative model that rewards architects based upon the performance of a building, thereby, stimulating engagement with the lifecycle of the building and acknowledging the dynamic nature of a building.

Finally, the participants highlighted the lack of knowledge available on ways to implement circularity in practice and, therefore, actively develop tools, methods and documentation to support the circular design process and tackle CE-related challenges in projects.

4.1.3 The changing role of the designer

The findings of Study A indicated how the context of a CE impacts the role of the designer in practice.

Firstly, the participants described how collaboration between actors across value chains becomes more crucial in the context of the CE in order to connect the different stages of a product's or building's lifecycle, and that this, therefore, becomes an integral component of the design process. Stakeholder management becomes more important when all the relevant actors are already included early in the design process.Agencies take an active role in establishing connections between clients, suppliers, manufacturers and other actors in the value chain. Furthermore, they take an active role in facilitating collaboration for a CE; for example, through offering a collaborative platform that invites different actors, unlikely partners or competitors to an intensive co-design process or 'design sprint' to address larger environmental and systemic questions together and challenge the traditional silo thinking that exists within individual organisations.

Secondly, both the interviewed industrial designers and architects emphasised that designing for a CE requires extensive business and economic knowledge to be able to design and convince clients of circular value propositions, the financial benefits of which are typically only apparent when considering extended or multiple lifecycles of products and buildings. Circular product design relies on the combination of the physical design and the business model, which requires that both aspects are simultaneously considered and developed early in the design process.

Finally, the findings indicated how designers act as change agents in the context of the CE. Some of the discussed design projects were less about the actual design of some physical artefact and more about challenging the existing 'linear' mindset and making circularity questions and challenges tangible and actionable. The participants in the study found it generally important to raise awareness and understanding of the CE and utilised various strategies (e.g., sharing successful cases; showcasing projects and exhibitions, infographics and storyboards) to elevate the CE from a conceptual discussion to a tangible and actionable one, thereby, creating alignment between the designer and client and internally within organisations.

4.1.4 External factors affecting circular design in practice

Study A also found several external factors (i.e., outside the capacity of design) that affect CE-related design practices. Policy and regulation seem to both positively and negatively affect the practice of designers. For example in architecture, the practice of reusing building components is hindered by current regulations in the building industry and challenges regarding the quality assurance of such components. Stricter requirements to provide environmental impact assessments of design proposals in turn stimulate designers to find optimal ways of lowering environmental footprints and create equal responsibilities amongst designers to adhere to such practices.

Another external factor relates to materials. Confusion and misconceptions exist amongst clients and consumers regarding 'renewable' and 'circular' materials. The choice of non-renewable materials such as plastics and metals in a design proposal may be justifiable from a circularity perspective taking into account the environmental impact over the optimal lifespan; however, negative perceptions of these materials can cause friction and challenges in design projects. Furthermore, although the reuse and repurposing of materials is generally considered to be a good practice, the aesthetical preferences and acceptance of consumers towards such materials affect and may inhibit the success of such design strategies in practice. For architects in particular, (reverse) logistics is currently a major challenge for the recirculation of materials in practice, both for practical reasons (e.g., storage of materials) and the associated environmental and economic implications.

Finally, the understanding and willingness that clients have towards the CE greatly affects circular design practices. To design products and buildings in a way that means they support circularity and facilitate extended lifespans and/or multiple lifecycles in many cases implies using different materials, new technical solutions or changes to existing manufacturing capabilities, for example. More value needs to be allocated in the design and manufacturing phase. Therefore, clients are often hesitant to engage and commit to the CE and a circular design approach due to the associated financial risks, higher costs of technical solutions and the perceived constraints of the current linear system. Additionally, the CE concept is often interpreted and understood in different ways by companies and designers. According to one of the participants, it is good to have collective terms and goals but 'being circular is not the solution to the problem', and it is important to consider the overall CE goals of reducing waste issues and climate impacts.

4.2 Study B - Circular design in practice and co-creation of the circular kitchen

This chapter summarises the findings of Study B, which aimed to gather insights about (1) the barriers and opportunities for the implementation of the CE concept within the kitchen industry and (2) to explore the role of co-creation strategies in facilitating CE awareness and CE-oriented innovation.

4.2.1 Changes in understanding and attitudes towards the circular economy

The findings of the study indicated that the workshop participants had developed an increased understanding of the CE, as well as an increased overall awareness of the CE during their daily practice. The issues that were emphasized by the participants were technical details such as extending the lifespan of kitchens and the reuse of kitchen furniture and components, along with the development of circular business models. Through working actively and creatively with the subject of circularity in the workshops, the participants began to think in 'such patterns' on a daily basis, and the workshops also indirectly contributed to changes in ongoing product development, such as scaling down the number of functionalities in an upcoming line of products.

4.2.2 Barriers for circularity in the kitchen industry

Based upon the interviews and workshops, several barriers for circularity were identified for the kitchen manufacturer related to (1) the costs of changing the current manufacturing capabilities; (2) a perceived lack of support from the supply and demand network; (3) the (reverse) logistics associated with resource circularity; (4) the complexity of the value and supply chain; (5) a lack of policies and regulations pertaining to CE for the entire industry; and (6) a lack of resources to focus on circularity in the company.

The key strength of the kitchen manufacturer involved is that it is able to provide a high level of specification and customisation of its products to customers, which has led to a broad product range with different colours, styles, dimensions and components. It became apparent during this study that this strength directly hindered practices that could lead to a greater level of circularity, as practices such as repairs, reuse and remanufacturing are greatly complicated when there is a low rate of interchangeability and compatibility between different products and components.

The co-creative workshops led to the idea of a modular kitchen concept based on a frame structure, which could facilitate an easier (dis)assembly process for the kitchen on site, the exchanging of components and support maintenance and repair practices during the kitchen's lifecycle. However, the company was sceptical of this direction because (1) this opposed the company's ideology of delivering pre-assembled kitchen furniture and (2) it would require major investments and changes to the current manufacturing capabilities.

4.2.3 Opportunities for circularity in the kitchen industry

Study B also identified two opportunities to promote resource circularity within the kitchen industry related to (1) adopting durable materials with a higher potential for recirculation and (2) the development of a PSS and service-based revenue model that could enable maintenance and repairs and avoid the premature disposal of kitchen furniture. Fibreboards such as chipboard and MDF have a relatively short lifespan and currently offer limited potential for recycling and repurposing, whereas alternative materials such as solid wood and bio-composites, respectively, were found to offer increased lifespans and allow for recycling practices.

The premature disposal and unnecessary and extensive renovations of kitchens that frequently occurs in Sweden could be addressed through a PSS, which could facilitate the tracking and recirculation of materials, components and kitchens as well providing a platform for the maintenance

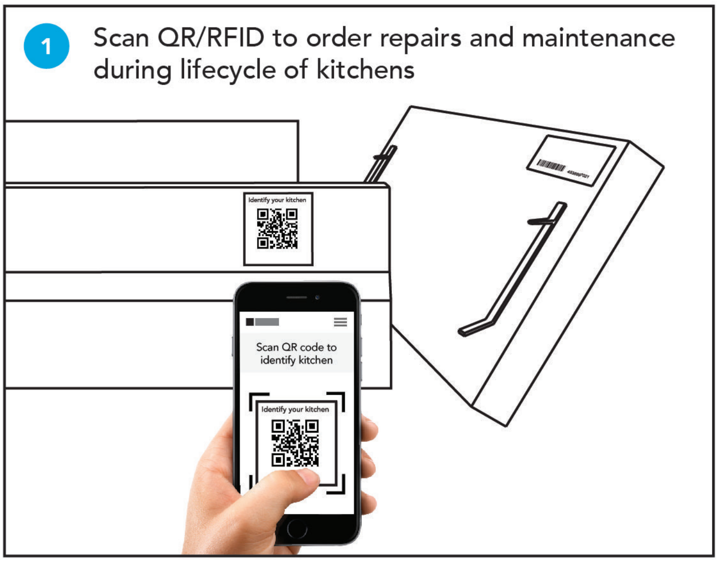

Figure 7. Proposed PSS solution enabling kitchen owners to identify components, request repairs and maintenance and facilitating the kitchen manufacturer with a way of tracking the recirculation of materials, components and kitchen furniture.

and repair of kitchen furniture. This PSS solution could provide end-users with a way of identifying furniture and components in need of repair or upgrades and service requests (See Figure 7) and act as a platform that enables reverse logistics and provides the manufacturer with information about the product's lifecycle and what parts tend to break and are replaced most often.

4.3 Study C - Supporting circular design through a card-based design tool

This chapter summarises the findings of Study C. During this study, the card-based circular design tool CfC was developed and utilised in a workshop with design experts with the aim of (1) deriving key learnings on circular design in practice and (2) exploring how design tools generally, and the CfC in particular, could support the process of designing for a CE. For a more detailed overview of the findings and the design tool, see appended Paper C.

4.3.1 Findings from the interactive survey and group discussion

The results from the interactive survey indicated that the participants considered the main challenges of designing for a CE to be strategic challenges (e.g., 'setting up collaboration and aligning stakeholders' and 'finding sustainable business models') as opposed to technical challenges (e.g., 'estimating the environmental impact of solutions over multiple lifecycles' and 'finding sustainable materials'). According to the participants, clients lack practical knowledge of how to implement circularity and are hesitant to engage with the CE because it often implies significant changes to the current capabilities and business models within companies.

Furthermore, the participants indicated that there is often a different understanding between the designer and client of what the CE implies in practice, and the participants stressed the importance of designers assuming the role of CE educators and convincing companies to engage with the CE. However, performing this role is considered to be challenging in practice due to the time pressure in design projects and a lack of successful examples demonstrating the value and feasibility of circular business models. One participant suggested that an ‘idea bank with good practical examples’ of circular design could help advance discussions with clients, inspire and broaden perspectives and demonstrate what is feasible.

The participants pointed out some challenges related to designing for a CE, such as maintaining a holistic perspective, predicting the consequences of design choices (e.g., material selection) and a lack of involvement once products are ‘on the market’. To advance the implementation of a CE, the participants mentioned that designers need to be well informed about business models, material alternatives and EoL scenarios and engage with stakeholders on a regional level such as material experts and recycling facilities.

4.3.2 Results of the design workshop utilising the cards for circularity

The groups considered the technical design and user context, showed awareness of lifecycle-related aspects and made deliberations regarding the average and optimal lifespan of different materials and components in the design process. Figure 8 provides a visual overview of some of the ideas developed by the groups. Two of the three groups also concretely considered business models and developed ideas for services related to their proposed (physical) design solution.

Overall, the workshop participants found the cards helpful in supporting idea generation and discussions within the scope of design for a CE. The design task was considered to be challenging, in part because of the complexity and variety of factors that needed to be considered. The number of cards in combination with the way the cards were organised on the tables was considered overwhelming and added to the complexity. The participants found it particularly challenging to use the ‘time’ cards that related to lifecycle aspects and emphasised that estimating the lifespan and environmental impact based on a design concept would require material experts and contextual knowledge of products and materials. Some participants also raised the crucial issue of ‘when can a design be considered to be circular?’, as a physical or technical design concept in itself does not

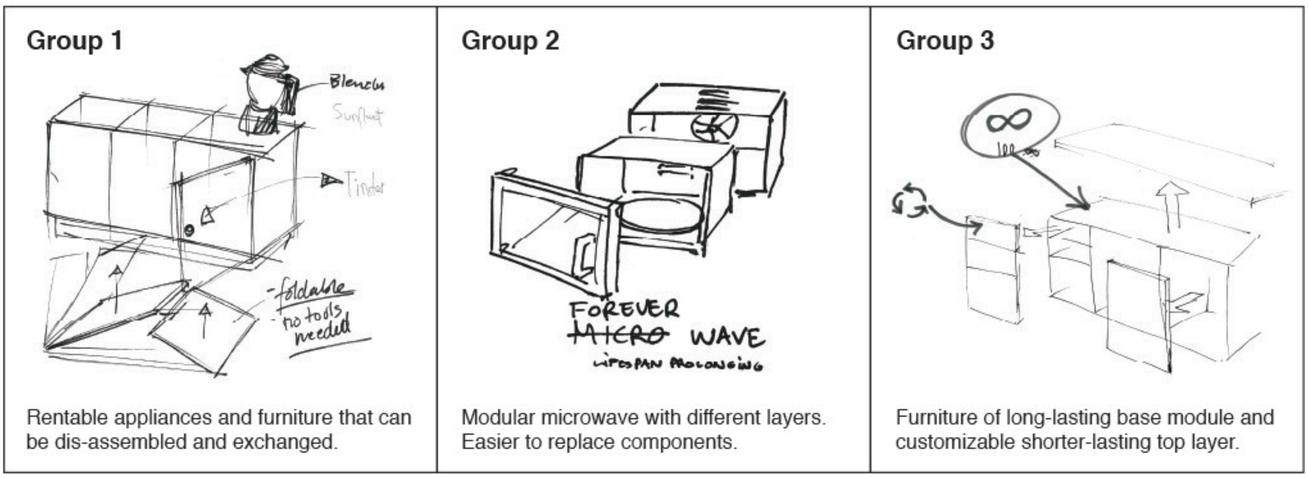

Figure 8. A selection of ideas generated by the participants for circular kitchen furniture and appliances based on the selected cards by each group in the workshop.

facilitate ‘circularity’ and it would also require some form of assessment to evaluate the extent to which different design ideas have the potential to support circularity. In addition to the generative function, the cards supported groups with different perspectives and levels of knowledge regarding CE to discuss strategies, find consensus and translate the cards into concrete ideas.

4.3.3 Key learnings on supporting circular design in practice

The findings of Study C indicate that a number of aforementioned barriers, already identified in the literature, were also experienced in practice by the participants, such as the lack of willingness of clients to engage with the CE and different interpretations and understandings of the CE, which hinder agreeing on uniform approaches. Based upon the findings of Study C, some key challenges regarding circular design were identified, along with ways in which these could be addressed through tools, strategies and methods.

First, tools and aids that help educate and convince stakeholders on the value and feasibility of circular design and business models could address the limited willingness to engage with the CE. Second, having an overview of practical examples (e.g., an idea bank) and case studies could inspire, broaden perspectives and help convey the feasibility of circular design and elevate it from a highly conceptual and theoretical discussion to a tangible one. Third, designers need knowledge on business models, material alternatives and lifecycle considerations, and methods to tackle the specific design challenges related to circularity, while maintaining an overall holistic perspective on the underlying goals of a CE to manoeuvre through the overall complexity. Finally, tools and ways of aligning CE definitions and perspectives and facilitating collaboration between actors could potentially address the discrepancies in CE understanding and lack of value chain collaboration.

5. Discussion

The main aim of this study was to investigate how the CE concept is currently interpreted and operationalised within design practice. Additionally, the thesis investigated what knowledge, tools and strategies might further support design for a CE and explored the role of collaboration and co-creation in design practice to enable CE-oriented innovation. The discussion section is divided into three sections that discuss the findings in relation to the different research questions and previous research.

5.1 Interpretation and operationalisation of the circular economy in design practice

RQ1: How is the concept of a CE currently interpreted and operationalised across the design practice of architecture and industrial design?

5.1.1 Circularity across the practice of architecture and industrial design

Based upon the findings of Study A and Study C, it is apparent that the CE represents a new though not entirely unique challenge for designers, which adds additional layers of complexity to design practice and requires designers to become even more aware of spatiotemporal parameters and holistic design approaches to be able to 'zoom out' and develop design solutions that consider the interactions between the different implementation scales (micro, meso, macro) and components in systems (e.g. business models, different value chain actors) that are necessary for the narrowing, slowing and closing of resource flows. In the second half of the 20th century, the complex and interdisciplinary challenge of sustainability expanded the working space of designers and the object-centric thinking to a more system-based design approach (Ceschin & Gaziulusoy, 2016; A. I. Gaziulusoy & Brezet, 2015; E. Manzini & Vezzoli, 2003). It seems that now, in the context of a CE, this trend will only continue to grow.

Earlier research has emphasised the need for systems thinking and design in the context of sustainable design (Blizzard and Klotz 2012; Charnley, Lemon, and Evans 2011; Gaziulusoy and Brezet 2015; Joore and Brezet 2015; Lambrechts et al. 2019; E. Manzini and Vezzoli 2003; Vezzoli et al. 2015) and recently also in the context of design for a CE (Bocken et al. 2016; De los Rios et al. 2017; Moreno, De los Rios, Rowe, Charnley, et al. 2016). The participants in Study A, primarily the industrial designers, mentioned that the CE requires thinking and designing in 'systems', yet it remains unclear how this process is facilitated in practice, and whether it is a natural and integral part of the design process or a conscious approach that is supported through particular tools or methods. According to Charnley et al., designers have been provided with little guidance concerning how these techniques [whole system design] should be implemented efficiently within an operational and substantially complex design process (Charnley et al., 2011). It is perhaps unsurprising that systems thinking and design was explicitly mentioned by the industrial designers, as this has been an integral component of designing service-based platforms and PSS solutions, which have been extensively discussed in the context of product design over the last two decades (e.g., see Brezet, Diehl, and Silvester 2001; Tukker 2004) and only recently discussed more intensively in the context of a circular built environment (e.g., see Ness and Xing 2017).

Based on the findings of Study A and Study C, designing for a CE further expands the scope, length and costs of design projects and the design process as it requires extensive interdisciplinary knowledge (e.g., of materials, business models, biology, value/supply chain structures) and typically requires more stakeholders to be involved (and managed) at the beginning of the design process. Study A indicates that design agencies experience CE-related knowledge gaps and address this by assembling dedicated circular internal teams and 'research' labs, including external experts in the design process and internalising the necessary and missing knowledge. Earlier studies have discussed what knowledge, skills and competencies designers must develop to be better equipped for CE-related design challenges (Andrews, 2015; De los Rios et al., 2017; Sumter et al., 2020, 2021), and Study A complements these with some insights into how CE knowledge generation is approached in design practice.

For both the architects and industrial designers in Study A, the design process in the context of a CE becomes increasingly data-driven (e.g., to accurately assess and track lifecycles) and some agencies have invested in data solutions (e.g., data analytics) to support the design process.

New digital technologies, IoT and data-driven solutions (e.g., material passports, digital twins) are considered to be enablers to connecting and closing resource flows (Alcayaga et al., 2019; Ingemarsdotter et al., 2019). These solutions can provide information about the present use, recovery and reuse of materials and components and inform designers and decision makers about the technical and spatial reversibility of design solutions (Debacker et al., 2017). In addition, as physical artefacts are increasingly becoming smart and 'living' assets that provide feedback, they could further support architects and industrial designers in understanding and optimising the lifespan of products and buildings and enable them to remain involved with the lifecycles of designed artefacts during and after the use phases.

Study A indicated how the participating industrial designers and architects interpret and operationalise the CE concept in design practice. Thus far, the architects studied have predominantly focused on the reuse of existing (waste) materials and components for the design of new buildings and structures, thereby, limiting the use of virgin materials and lowering the ecological footprint. To a lesser extent, the architects discussed how buildings and building components can be designed so that they can be easily disassembled (DfD) and reused in the future, and how the lifetimes of buildings can be prolonged through designing in a way that facilitates easy maintenance and repair (e.g., modular design). Making use of existing and waste construction materials and components in design practice implies that greater flexibility needs to be adopted in the architectural design process, as it is uncertain what materials and components may be identified, which shifts the design process from being goal-oriented (the design is driven by predefined goals) to means-oriented (the design is driven by available means; De Jong and Van der Voordt 2002). The practical implications of such developments for the architectural design process have been discussed for example by Cambier, Galle and Temmerman (2020), Galle et al. (2015), Kanters (2020) and Kozminska (2019).

The industrial designers in Study A engaged with the CE by designing durable long-lasting products; designing modular products to facilitate easier disassembly, repair and maintenance; and developing circular business models that rely on the combined design of a physical product and a PSS. Thus far, it appears that circular business models and service-based solutions have received greater attention in the context of industrial design and on the micro level (products) rather than the meso level (buildings). Kanters (2020) has highlighted that the increased complexity of the building scale in regard to stakeholders, particularly in regard to ownership, could be a possible explanation for this. Nevertheless, PSS solutions may offer uncaptured potential in the context of the built environment, for example, in facilitating more efficient use of buildings (e.g., sharing principles), and maintenance activities and service life extensions, which could decrease resource consumption and the growth of the building stock (Fargnoli et al., 2019; Joensuu et al., 2020).

In contrast to architecture, the reuse of waste materials appears to be more of a niche design strategy within industrial design, which mostly appears in the form of 'upcycling'. Yet, one of the cases discussed in Study A (the upcycled stool incorporating off-cuts from wooden chairs) interestingly showed how an upcycled product can also serve as a statement and knowledge object, which in this case led to wider awareness, discussion and changes within the particular manufacturing company in regard to resource efficiency.

5.1.2 The intersection of industrial design and architecture and a universal approach

One might wonder why it is relevant to investigate the practices of both industrial design and architecture. Pomponi and Moncaster (2017) investigated CE research in the built environment and argued that solutions that are suitable for manufactured products are unlikely to be applicable to buildings, as buildings are unique, complex, long-lived and ever-transforming entities once assembled, and the manufacturing and useful lifespan extends over a significantly longer period of time. According to Study A, the challenge of a CE thus far has revealed certain different foci amongst architects and industrial designers in practice but also similarities. The results also show that the transition to a CE presents design challenges at the intersection of industrial design and architecture, whereby, industrial designers can contribute to 'user-centred' questions and advancements in PSS solutions and business models to promote a circular built environment, while architects can contribute to crucial spatial challenges in the circular design of products, such as the (reverse) logistics of the products, components and materials and the types of facilities that are needed to find optimal ways of facilitating maintenance and repair activities in increasingly dense and complex urban environments. Hence, investigating synergies and exchanges of circular design knowledge amongst different design disciplines may lead to fruitful insights on how to advance the CE as a whole.

As Study A has shown, products and buildings can be designed so that they are easily disassembled, repaired, maintained, reused and recycled, yet such design strategies are insignificant if they are not complemented by a system consisting of business models and incentives (financial, user-related) that motivates such practices to occur. This emphasises the importance of a holistic design approach and the way in which the CE is understood as a systemic shift (Kirchherr et al., 2017) with clear definitions and indicators for circularity (Geng et al., 2012; Moraga et al., 2019).

Study A indicated that the different R-imperatives (e.g., reduce, reuse, recycle) form a common CE vernacular for designers but some terms are also used in fundamentally different ways, whereby, reuse for architects primarily relates to reusing building waste, spare materials and components for the design of new structures, while reuse for industrial designers refers to how products could be reused by another consumer in future use cycles. This appears to be in line with Reike, Vermeulen and Witjes (2018), who emphasised the conceptual ambiguity that exists across the R frameworks and stressed that a shared understanding of key notions is critical for the successful implementation of a CE, as 'different languages and professional jargon are used by stakeholders possessing different underlying paradigms' (p.254). The different R frameworks can provide a coherent taxonomy of circularity strategies but thus far have been mainly targeted towards the micro level (products, components) and are less applicable for the meso (buildings) and the macro levels (cities, built environment). As the CE blurs the boundaries of scale and discipline, it is vital to support design practice and education with a common design language and universal design frameworks that can help to ensure a holistic approach and that also consider the different implementation levels of the CE. In this regard, visual representations, such as the one presented in Subchapter 2.4, which communicate circular design strategies that are relevant for multiple implementation scales could be helpful.

5.1.3 The effects of the circular economy transition on the practice of design

Study A indicated that in the context of a CE, the predominant linear logic in the business model of design consultancies is increasingly being questioned. Still, both architectural and industrial design projects are most often based on temporary engagements after which the design is 'handed over' to the client. This limits the involvement and engagement of designers in regard to the lifecycle of designed artefacts and may lead to missed opportunities in terms of circularity, especially as CE-related design challenges are likely to appear in the use phase (Sumter et al., 2018). Some design practitioners (aim to) pursue alternative models and services based on long-term engagements and capturing value throughout the lifecycle of artefacts, which could also enable designers to become more aware and better understand how designed artefacts 'wear and tear' (Lilley et al., 2019). Galle et al. (2015) highlighted that in the value chain of construction, the involvement of architectural designers only represents a short period relative to the long-term impact of their choices, while it is precisely the architect who can help ensure long-term value through lifecycle thinking and the well-considered management of buildings.

The findings of Study A and Study C indicate that CE awareness amongst clients, and the willingness to engage with it, is an important factor in the success of design efforts that strive to promote circularity. Clients are considered hesitant due to the associated financial risks, higher costs of technical solutions and the perceived constraints resulting from the current linear system. This is consistent with the general CE barriers identified in previous studies related to hesitant company cultures and a limited willingness to change, a limited willingness to collaborate in the value chain, the existing linear system and attitudes to and knowledge of the CE (Kanters, 2020; Kirchherr et al., 2018; Ritzén & Sandström, 2017; Rizos et al., 2016). The findings of Study A indicate that designers play an important role in addressing these barriers and aligning CE perspectives, definitions and understanding between the stakeholders involved in the design process. Study A also showed that design practitioners utilise various strategies to elevate the CE from a conceptual discussion to an actionable one and create alignment between the stakeholders. Sumter et al. (2021) consider this skill to be a key competence for circular design, which they have defined as 'circular economy storytelling', that is, the ability to create engaging visions and narratives of the CE in order to make it a shared idea for which support can be garnered among various stakeholders.

Policy and regulations are also considered to play an important role in enabling circular business models and design strategies (Moreno et al., 2016). This was also expressed in Study A, in which a perceived lack of regulations and policies that support circularity was highlighted. However, positive developments are also occurring such as stricter regulations regarding the calculation of the environmental impacts of design proposals, thus, creating equal responsibilities amongst designers for a CE.

Finally, a crucial factor for design practice and the transition to a CE is consumer behaviour and the acceptance of circular value propositions (Lofthouse & Prendeville, 2018; Selvefors et al., 2019; Wastling et al., 2018). Ultimately, people's behaviour is a deciding factor in the success of resource recovery and the widespread adoption and acceptance of circular business models and circularity principles in design. However, the users' perspective was only mentioned in the studies to a limited extent with regard to aesthetical preferences and the acceptance of materials and material design challenges.

In this regard, aesthetical preferences and the acceptance of materials that are reused or repurposed do need to be further investigated, as these affect the success of certain design strategies (e.g., upcycling), as illustrated by the case in Study A of the flooring material that was reused as wall cladding but was not the first choice of the tenants. Consumer acceptance of circular offerings has been discussed (Gullstrand Edbring, Lehner, & Mont, 2016; Tunn, Bocken, van den Hende, & Schoormans, 2019; Van Weelden, Mugge, & Bakker, 2016) and the acceptance towards repurposed materials has been investigated to some extent in the built environment (Sieffert, Huygen, & Daudon, 2014).

Furthermore, practitioners are faced with paradoxical circular design challenges in regard to materials due to confusion and misconceptions amongst clients and consumers regarding 'renewable' and 'circular' materials. Negative associations towards unrenewable materials such as metals and plastics and a positive bias towards renewable materials such as wood may in some cases constrain designers from developing the preferred circular solution, as the choice of certain non-renewable materials might be justifiable from the perspective of circularity and the environmental impact over optimal lifespans.

5.2 Collaboration for a circular economy and the role of designer

RQ2: What is the role of stakeholder collaboration and co-creation in design practice as a way of facilitating CE-oriented innovation?

In Study B, which explored the potential for circularity in the kitchen industry, it was apparent that the most prominent design challenge did not relate to technical capabilities or technical changes to the design of kitchens but rather to intangible challenges such as fostering CE understanding and engagement amongst stakeholders and identifying and engaging the other stakeholders in the value chain who are needed to support circularity. This is in line with previous studies that indicate that the major barriers for a CE are not of a technological nature but rather are cultural and organisational such as the limited willingness to collaborate in value chains (Kirchherr et al., 2018) and limited support in the supply and demand networks (Rizos et al., 2016).

The participants in Study C also emphasised the strategic challenges (e.g., 'setting up collaborations and aligning stakeholders' and 'finding sustainable business models'). According to Leising, Quist and Bocken (2018), CE collaboration is reliant on personal ambitions and difficult to achieve when the actors lack high-level ambitions.

The co-creative design approach adopted in Study B, which actively involved the kitchen manufacturer in the design process, proved to be helpful not only for ensuring an inclusive and participatory approach but also functioned as a way of fostering CE awareness and knowledge amongst the participating actors and equipping them with a CE mindset and 'toolbox'.

The kitchen manufacturer demonstrated uncertainty concerning whether and how to collaborate with suppliers to recirculate components and materials. This uncertainty corresponds with the finding in Study A that companies often struggle to collaborate outside of their own organisational structures. It is exactly here where designers can act as 'connectors' and facilitate connections and collaborative spaces for circular innovation. Previous research has discussed the role of designers as connectors (Ezio Manzini, 2009) who can facilitate strategic dialogues between actors (Meroni, 2008), establish future visions and act as agents of change (Banerjee, 2008). The findings of Study A illustrate how design practitioners are performing and claiming such roles in practice and the discussed cases show how facilitating connections and collaborative space are considered vital elements in the success of design projects.

Facilitating effective collaboration between actors in the design process also appears to be linked to the competencies of designers. Kanters (2020) argued that architects can play a central role in linking actors but would require additional knowledge (e.g., leadership qualities). Sumter et al. (2020, 2021) defined 'circular economy collaboration' as a specific competence for industrial designers and found this to be one of the most frequently utilised competencies based on a survey of 128 design practitioners working on CE projects. In the context of a CE, closing resource flows on a systemic level might require dialogues and collaboration between actors who are typically competitors with conflicting interests. The findings of Study A illustrate that some agencies specialise in facilitating 'neutral' collaborative platforms and co-design processes as an offered design service. In this sense, more agencies are reinventing themselves and offering CE-focused skills and services that support the closing of resource loops, such as RotorDC (n.d.), who utilise a team of 'deconstructors' and own facilities to enable the storage, sale and reuse of salvaged materials and components. In addition, Superuse Studios (n.d.) run a digital platform or online 'Harvest Map' which locates waste materials on an interactive map to highlight them as an opportunity for nearby architects and building projects.

Pedersen and Clausen (2019) investigated the process of co-design for a CE and emphasised that the key to success is not solely the design of material objects but rather the design of the stakeholder network and relationships. However, in practice, the success of design projects is still most often measured by their physical and tangible outputs. As shown in Study A, the 'design' activities that foster stakeholder connections, collaboration and networks were not mentioned, documented or visualised as a concrete outcome of the design process. To advance CE collaboration competencies in design practice and education, it may be beneficial to further adopt CE collaboration as an integral part of the (circular) design process and as a crucial parameter in CE-focused design projects. Furthermore, CE collaboration needs to be considered in future design training, methods and strategies to sufficiently support design practitioners and students in tackling the complicated challenges of a CE encountered in practice, which often require cross-disciplinary collaboration and co-creation.

5.3 Knowledge, tools and strategies to support circular design in practice

RQ3: What knowledge, tools and strategies could further support design for a CE in practice?

Based upon the practice-based insights gathered in Study A and Study C, it seems that the CE necessitates a holistic design approach that requires designers and architects to increasingly develop extensive interdisciplinary knowledge, for example, in regard to business thinking, stakeholder management, materials and environmental impact assessments. The business-related challenges and aspects of design, for example, are integrated and well-established in the domain of strategic design, and some design agencies specialise in providing ‘business design’ as a service.

The question of what capabilities need to be fostered among designers and architects to address the CE in design practice and education appears to represent a challenging duality. On one hand, one could argue that specialists best address specific design challenges, and in this regard scholars such as Rios et al. (2017) argue for different CE ‘design personas’, such as the ‘product-service designer’ and the ‘retrofitting designer’. However, such an approach also entails the risk that a certain degree of silo thinking and the compartmentalisation of relevant CE design knowledge might be maintained. On the other hand, one could argue that systemic challenges such as the CE require a ‘generalist’ approach and a balance between discipline-specific and trans-disciplinary skills (Charnley et al., 2011). In this regard, Sumter et al. (2021) provide a coherent and comprehensive overview of the CE key competencies for design, which could be useful for design education and serve as a ‘template’ for assembling interdisciplinary design teams in practice. The inquiries into design practice included in Study A illustrate that in the context of the CE, every technical design challenge is also a business challenge. One may have excellent and creative technical design proficiency and proposals, but ultimately innovation for a CE requires designers to find the promising synergies between the technical, business, environmental and societal challenges and these are more likely to result from a holistic approach that elaborates on these different pillars.

As the CE blurs disciplinary boundaries, it will not be surprising to see closer collaborations and synergies between different types of designers emerge (e.g., architects, industrial designers, service designers, strategic designers), such as the ‘New European Bauhaus’ that the EU envisions will help Europe move toward a CE (European Commission, 2020c).

Study C identified a number of challenges for circular design relating to client willingness towards and understandings of CE, the complexity of the lifecycle thinking and the interdependent parameters and the fact that design for a CE tends to remain on a highly conceptual and theoretical level. The card-based design tool (CfC) developed in Study C made an attempt to support designers (and other actors) with a holistic design approach that distinguishes the relevant interrelated parameters of the (technical) design strategy, business model and industrial models (relating to value chain interaction and networks). Hence, it encourages systems thinking and exploring the synergies between the different parameters within ideation and conceptualisation processes. Many design tools have been developed in the context of the CE, for example, to support CE collaboration (Brown et al., 2021b; Konietzko, Bocken, & Hultink, 2020a; Leising et al., 2018), business model innovation (Baldassarre et al., 2020; Bocken et al., 2019), design synthesis and conceptualisation (van Stijn & Gruis, 2019) and overviews of circular strategies (Blomsma, Pieroni, et al., 2019; Van Dam et al., 2017). However, the tools are seldom validated in practice or utilised as a way to generate knowledge about CE design and innovation processes. In Study C, the tool was tested not to primarily evaluate the effectiveness of the tool but rather to investigate the interpretation and operationalisation of the relevant circularity principles and parameters in the design process. Roy and Warren (2019) argued that card-based design tools in particular can provide a common basis for understanding and communication in a team and tangible external representations of design elements or information. The CfC showed potential as a generative toolkit that describes a participatory design language (Sanders, 1999) and a way of staging discussions on definitions and strategies regarding circularity and aligning perspectives in a multi-disciplinary and multi-stakeholder context.

Finally, Study C indicated the need for overviews of case studies and practical examples of circular design to convey the feasibility of the CE to clients and support ideation processes by translating and transferring principles from existing solutions to new contexts. This demand corresponds with that expressed by Cambier, Galle and Temmerman (2020), who discussed the oversupply of design tools addressing the basic principles of circular building in the context of the built environment and called for structured and detailed overviews of practical examples and best practices for circular building. Although the use of examples in the design process might result in 'design fixation', the presence of examples may also lead to improved novelty and quality in design ideas (Sio, Kotovsky, & Cagan, 2015).

5.4 Limitations

The main limitations of this thesis are the use of primarily qualitative data, the sample size of the studies and the limited geographical scope. The aim of this thesis was explorative in nature and, therefore, the studies did not provide statistically relevant sample sizes to be able to generalise the findings. Nevertheless, the richness and depth of the findings contributes to the theoretical and practical relevance of the research and identifies multiple directions for further research.

Since Study B and Study C were positioned in a Swedish context, and Study A in a northern European context, I also acknowledge that this represents a limited geographical scope in which the different countries display similar sociocultural and socioeconomic conditions. Despite the fact that various countries within this geographical scope were relevant to investigate because they are regarded as front-runners in the advancement of the CE, there may be differences in regard to how the CE concept is interpreted and operationalised in design practices across the world in different cultural and geographical contexts and under different economic and political conditions.

5.5 Reflection on the research design and methods

To date, limited empirical investigations have been conducted regarding design practices for a CE. Therefore, the aim of the research was explorative, and the studies utilised a primarily qualitative inductive approach. The inductive approach, including mainly semi-structured interviews as data gathering, enabled the uncovering of new concepts and allowed for fieldwork without being constrained by predetermined categories of analysis, which contributed to the depth, openness and details of the qualitative inquiry (Patton, 2002).

It should be noted that the field of DfS is extensively studied and well-developed, and many of the developed design theories and methods are also relevant for design for the CE. Therefore, a more abductive approach towards the research would also have been appropriate, which could have focused on an extensive literature review study of DfS to firstly develop the theoretical framework and then study the practice to help refine the existing ideas in design theory in the context of the CE. However, the technological, environmental and social paradigms are rapidly changing, and according to Bakker, Mugge, Boks and Oguchi (2021), what used to be valid design strategies and guidelines two decades ago are not necessarily valid today, which requires us, to some extent, to continuously 'reinvent the wheel'.

The inductive approach adopted in this thesis does not mean that this is theory-free research, as such a phenomenon does not exist (Guba & Lincoln, 1994). However, after establishing an elemental understanding of the relevant literature and basic concepts, there is a value in possessing a level of 'semi-ignorance' with regard to the literature, that is, not knowing the literature in great detail because being extremely familiar with the literature too early can result in myopia and may lead to confirmation bias (Gioia et al., 2013).

Although qualitative approaches have been critiqued for their lack of rigour, and inductive research for its weakness in demonstrating scientific advancement (Goldthorpe, 2000), the qualitative rigour can be enhanced through systematic approaches to inductive and new concept development such as the methodology developed by Gioia, Corley and Hamilton (2013). This methodology was adopted in the data gathering and analysis of Study A and offered the advantage of first being able to apply an informant-centric approach or first-order analysis (which prominently represents the interviewees' voices to enable the discovery of new concepts). This was followed by a second-order analysis that utilised researcher-centric concepts, themes and established overarching theoretical dimensions.

I realise that the chosen inductive approach combined with a broad research scope (both architecture and industrial design) in a sense led to more questions than answers and enabled just the 'scratching' of the surface. A different research approach (e.g., quantitative or focusing more on deductive logic) combined with a narrowly defined research scope could have provided more specific, rigid and generalisable findings but might have missed some of the relevant themes resulting from the broad array of findings in this thesis that now support many interesting avenues for further research.

Finally, I offer some reflections on the applied RtD research approach, which utilised methods and processes from design practices as a legitimate method of inquiry. This approach has also been criticised for its lack of rigour, as the design research community has not yet firmly established what the approach constitutes; the criteria for evaluating the quality of the contributions; or discovered a common method for documenting the knowledge, methods, theories and insights that emerge from this type of research (Zimmerman et al., 2010). This issue emphasises the need for clearly articulating and documenting the theories and knowledge that result from the RtD approach and disseminating these to the cross-disciplinary platforms that can use these insights for the growth of the theory (Stappers, 2007). This was attempted in Study C by not only documenting the tool but formulating the key lessons that resulted from applying the tool in the design workshop context. In this thesis, the strength of the RtD approach was seen in its ability to allow for designerly activities in a complex reality (the CE), enabling the researchers to focus on the future, rather than the present or past.

6. Conclusion and future research

This thesis investigated the current interpretation and operationalisation of the CE concept across the practices of industrial design and architecture. Additionally, it explored potential ways to advance design for a CE in practice through collaborative approaches and appropriate knowledge, tools and strategies.

Study A gathered insights on current CE practices from design practitioners across architecture and industrial design and found that the complex and multi-faceted challenge of a CE is expanding the scope of design projects and driving the integration of new knowledge fields and skills within the design process. Extensive collaboration is needed with stakeholders and experts throughout all stages of the design process and the results indicate that designers in practice facilitate connections and collaborative spaces that foster collaboration between actors, which can play a crucial role in the success of CE-centred design projects. In the context of the CE, the focus of designers is shifting further away from the creation of physical artefacts to the creation of systems, business models, collaborative networks and future visions; thus, ultimately helping clients to look ahead and render the pathways towards circularity tangible. Design agencies are responding to the CE by establishing dedicated CE research and design teams, facilitating knowledge exchange, developing circular strategies and methods and pursuing long-term client relationships that aim to promote circularity and the engagement of designers with the lifecycles of designed artefacts rather than seeing design projects as temporary endeavours. Furthermore, industrial designers and architects appear to approach the CE differently in practice. As the CE blurs boundaries of scale and discipline, it is recommended that a common CE design language and framework is implemented to ensure a holistic and integral approach that ongoingly considers the underlying CE goals of contributing to sustainable development and establishing a systemic shift in resource consumption.

Study B reported on a series of design workshops with a kitchen manufacturer and explored the role of co-creation strategies in facilitating CE awareness and innovation. This study indicated that a co-creative design approach that actively involves actors in the design process can foster CE awareness and knowledge among the participating actors. The study indicated there is potential for circularity in the kitchen industry in the form of adopting durable materials and a PSS concept, which could promote resource recovery and lifetime extensions for kitchen furniture. However, it also identified barriers relating to internal factors and capabilities and a perceived complexity and lack of support within the value- and supply-chains.

Study C gathered practical insights on design for a CE through an interactive survey and a design workshop that utilised the card-based circular design tool CfC. The findings indicated that design for a CE remains highly conceptual and generating design concepts for a CE during the workshop was perceived as challenging due to the complexity of the involved spatiotemporal parameters and difficulties in assessing circularity. A call has been made for practical examples of circular design and tools that can generate a shared understanding and engagement between stakeholders and convey the feasibility of circular design and business models. The developed CfC showed potential not only as a generative tool but also as a tool that can promote discussions on CE definitions and strategies and help align perspectives in multi-disciplinary contexts.

Overall, the findings of this thesis contribute to a better understanding of how the concept of a CE is currently implemented across design practice and identified pathways to further advance design for a CE. These insights are relevant for practitioners seeking to better understand the complex reality of a CE and the important factors and interdisciplinary challenges relating to design. Given the current practical advancements of the CE in the EU and the rapid rate of technological development, there is a need for practice-based research and generating knowledge 'through design'. The findings of this thesis could be relevant for design researchers and curricula intended for the growth of CE theory and to inform the development of appropriate design methods, tools and guidelines.

To conclude, this thesis emphasises the need for a holistic and systemic approach towards design for a CE that goes beyond perceiving the CE as a merely technical design challenge and design projects as temporary efforts. Successful design efforts in the context of a CE rely on extensive collaboration with all the relevant actors in the value chain during design projects and partnerships that extend throughout the lifecycles of designed artefacts. Thus, collaboration as well as participatory design approaches should be considered integral components in design for a CE, and the 'design' and alignment of stakeholder networks and relationships should not be overlooked as concrete but valuable intangible design outcomes.

Furthermore, there is an ambiguity and multitude of definitions surrounding the CE, and practitioners seem to interpret the CE in different ways (including industrial designers and architects). It, therefore, seems necessary to investigate the implementation of a common design language and universal design frameworks and explore ways and tools to align definitions and perspectives on CE in a multi-stakeholder context. Finally, an additional contribution of this thesis is the provision of the combined perspective of industrial design and architecture, which are two design disciplines that are not typically investigated together but are certainly expected to interact more closely in the transition to a CE.

6.1 Future research

The explorative nature of this thesis and the fact that it is based primarily on qualitative inquiries means that the results should be considered as tentative but also provide many directions for further research. I have identified the following future directions for research:

- This research has mainly focused on the perspective of designers to gather rich and deep insights from the perspective of design in particular. However, to gain a more comprehensive understanding of the key factors and important challenges in design efforts for a CE, it is recommended that the perspectives of multiple stakeholders in the design process, including clients, value chain actors and end-users, are also investigated.

- The interview as research method is helpful in providing a momentary snapshot of an individual's perceptions and experiences, but it does not gather insights on how people act in practice nor how their attitudes and behaviours develop over time. Longitudinal case studies that follow CE-oriented design projects over time could allow for rich observations and provide more context and deeper insights into how the circular design process is coordinated, structured and adapted across different stages from the perspective of multiple actors.
- The findings of Study A could be consolidated through larger sample sizes that consider additional design disciplines and/or geographical and cultural contexts to gather deeper insights on how circularity is implemented across different design disciplines and implementation scales and to identify ubiquitous factors as well as differences. This would also require further investigation into other design disciplines that interact with the CE, such as fashion and textile design, interior design and interior architecture. Here, a quantitative approach such as a survey would enable triangulation and could be interesting in terms of validating the findings of Study A and ascertaining the extent to which they are represented on a wider scale in practice across different contexts and disciplines of design.
- It seems vital to define common and universal design frameworks and language for circular design to align definitions and perspectives across different design disciplines to ultimately support a holistic design approach towards the CE.
- There is a need for tools that help facilitate discussions on perspectives and strategies in regard to circularity and align these perspectives in a multi-disciplinary design context with multiple actors and there is a call for practical examples of how circular design can be implemented. In this regard, the CfC's potential to function as a generative tool for circular design and as a way of staging discussions and aligning perspectives on circular strategies in a cross-disciplinary context will be further developed and evaluated. Future research could also focus on evaluating the CfC within design curricula and with different types of designers and actors to provide insights on different perspectives and approaches regarding design for a CE and evaluating the usefulness of the tool in a wider sense.

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Appended papers A-C

Paper A

Dokter, Giliam, Thuvander, L., & Rahe, U. (2021)
How circular is current design practice? Investigating perspectives across industrial design and architecture in the transition towards a circular economy.
Sustainable Production and Consumption, 26, 692–708.
https://doi.org/10.1016/j.spc.2020.12.032

Paper B

Dokter, G, Andersson, S., Thuvander, L., & Rahe, U. (2020)
Co-creation – a facilitator for circular economy implementation? A case study in the kitchen industry.
In N. Nissen & M. Jaeger-Erben (Eds.), PLATE Product Lifetimes And The Environment 2019 – Conference Proceedings. TU Berlin University Press. ISBN 978-3-7983-3125-9 (online).

Paper C

Dokter, G., van Stijn, A., Thuvander, L., & Rahe, U. (2020)
Cards for circularity: Towards circular design in practice.
IOP Conference Series: Earth and Environmental Science, 588(4).
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